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CLIMATIC NORMALS AS PREDICTORS
Part 2: Extension

by

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01730

AFCRL-68-0673

C L I M A T I C   N O R M A L S   A S   P R E D I C T O R S

PART 2: EXTENSION

BY

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Scientific Report No. 2

Contract AF 19(628)-5716

Project No. 8624 Task No. 862402
Work Unit No. 86240201

1 November 1968

Contract Monitor: Iver A. Lund
Aerospace Instrumentation Laboratory

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Prepared for

Air Force Cambridge Research Laboratories

Office of Aerospace Research

United States Air Force

Bedford, Massachusetts

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ABSTRACT

Temperature and precipitation for a single month or year, picked at random, at each of seven United States stations are found to be estimated as closely, on the average, by the mean of the preceding 10 to 40 years as by a 30-year "normal." The median value for the preceding 15 or so years may be an even slightly better estimator. Graphs show the mean square and mean absolute differences between k-year means and the next observation for $k = 1 [1] 50$, and the mean absolute differences between k-year medians and the next observation for $k = 1 [2] 49$, for Dodge City, Vicksburg, Memphis, Cairo, Madison, Pittsburgh, and Lynchburg. Comparison of these graphs with corresponding graphs based on random normal numbers, biased in various ways, suggests that many climatic records contain progressive changes in mean or in variance, or both. The number of antecedent years (k*) for which the mean or median is closest to the next year's observation varies erratically from month to month, but tends to be the same at nearby stations for a given month.

CLIMATIC NORMALS AS PREDICTORS, 2 : EXTENSION

1. Introduction

Confirmation, extension, and interpretation of the results of previous studies on the optimum averaging period for climatic data, when the average will be used to estimate next year's conditions, is the chief purpose of this Report. Further extensions and interpretations will be presented in future reports.

Scientific Report No. 1, henceforth designated as "SR 1", summarized and consolidated the findings of five previous studies. All were concerned with the average difference between a k-year average and a single value m years after the end of the k years, or an λ-year average beginning m years later:

```
              _______k_______ --m-- ___λ___
      . . . . . . . . . . . . . . . . . . . . . . . . . . .
i =   1 2 3                                               n
```

While this is the general formulation considered in the present study, the previous investigations were for single values ($\lambda = 1$) one year ahead ($m = 1$), except for one study in which the squared differences for prediction 1, 5, and 9 years ahead were averaged. For n observations ordered in time, $x_1 , x_2 , \ldots , x_n$, the mean squared difference between a k-year average and the next (k + 1st) value is

$$S_k^2 = \frac{1}{n-k} \sum_{i=1}^{n-k} \left[\frac{1}{k} \sum_{j=0}^{k-1} x_{i+j} - x_{i+k} \right]^2$$

This extrapolation variance s_k^2 and its square root, s_k, the standard error of extrapolation, were used by all except one of the previous investigators, and is the chief criterion of the present study. Two other plausible measures of extrapolation error, however, are also used:

Q_k, the mean prediction error, obtained by taking the absolute value, rather than the square, of the differences;

D_k, the mean prediction error of the median, defined as the mean absolute difference between the median of the antecedent k years and the $k + 1$st value.

In the previous studies, discussed in SR 1, and in the present extension, the chief interest is in k^* ("k-star"), the value of k for which s_k^2 is a minimum. It is generally less than 30 years, the officially-adopted length of record for a climatic "normal," in the previous studies of daily maximum, mean monthly, and annual temperatures, of monthly and annual precipitation, and of annual streamflow. To confirm and extend these findings, monthly and annual temperatures and precipitation amounts for seven United States stations were used to compute s_k^2 and evaluate k^*; other computations, for prediction more than one year ahead ($m > 1$), will be discussed in a later report.

The seven stations were all those in Vol. I (North America) of World Weather Records (1960) for which at least 85 years of complete data were given; actually all except one had 90 or more years. The seven, all in eastern or central United States, and the first year of complete data, are:

Dodge City, Kansas	1874
Vicksburg, Mississippi	1871
Memphis, Tennessee	1871
Cairo, Illinois	1871
Madison, Wisconsin	1869
Pittsburgh, Pennsylvania	1870
Lynchburg, Virginia	1871

All tables and figures present the data in this order, generally from west to east and south to north, up the Mississippi Valley.

Many U.S. stations have longer, and possibly "better," records. But the basic investigation seeks to establish what portion of a climatic record offers the best estimate of future conditions, at a reasonably good weather station, not a perfect one. These seven stations apparently had been deemed to have records sufficiently homogeneous and accurate to warrant world-wide use, and hence were suitable for study. Other stations, both in the U.S. and abroad, have been investigated, and will be discussed in future reports.

2. Discussion

For each of the seven stations, the mean squared prediction error, s_k^2 , was computed separately for monthly and annual temperature and precipitation, for k = 1,2,3, ..,50. The FORTRAN IV program, which also computes $s_{k/m}^2$ for m = 1 [1] 10, as well as $Q_{k/m}$ and $D_{k/m}$ and various ratios, is given in detail in Report No. 3. Results of these additional computations will be discussed later in this Report, and in subsequent reports.

As examples of the computational results, values of s_k^2 for annual temperature and precipitation at each of the seven stations are given in Tables 1 and 2 respectively. An asterisk indicates the minimum values of s_k^2 for each station, and hence identifies the appropriate k*. All values of s_k^2 for each month, and the year, for each of the seven stations were plotted on the same basic diagrams, six months (or all stations, for annual values) to a sheet.

The basic plotting sheet, used in SR 1, has lines of $s_k^2 = (1 + 1/k)\ s^2$, for various arbitrary values of s^2 . If all the elements in a climatic series be normally distributed, independently and identically, with means of 0 and common variance s^2 , the difference between one observation and a

Table 1. Values of S_k^2 of annual temperatures at seven stations.

K	DODGE C.	VICKSB.	MEMPHIS	CAIRO	MADISON	PITTSB.	LYNCHB.
01	13.912	16.330	13.742	13.912	14.151	14.276	13.444
02	6.123	8.913	6.902	6.776	7.325	7.110	6.866
03	4.467	6.620	5.641	5.073	5.192	5.158	4.838
04	3.629	5.638	4.799	4.128	3.983	4.192	3.768
05	3.214	5.170	4.411	3.775	3.461	3.920	3.530
06	2.269	4.374	3.901	3.052	2.992	3.302	2.764
07	1.897	3.905	3.335	2.590	2.697	2.917	2.510
08	1.542	3.411	2.862	2.252	2.499	2.634	2.358
09	1.503	3.456	2.627	1.993	2.247	2.368	2.174
10	1.289	3.381	2.104	1.659	1.905	1.966	1.552
11	1.190*	3.405	1.906	1.489	1.748	1.739	1.576
12	1.248	3.256	1.768	1.465	1.751	1.727	1.652
13	1.356	3.092	1.601	1.388	1.680	1.679	1.591
14	1.406	3.043	1.434	1.445	1.669	1.697	1.671
15	1.359	3.004	1.427	1.420	1.628	1.661	1.701
16	1.325	2.998	1.294	1.404	1.598	1.612	1.736
17	1.321	2.909	1.165	1.456	1.680	1.743	1.733
18	1.279	2.803	1.170	1.160	1.430	1.442	1.530
19	1.300	2.613	1.111	1.044	1.347	1.359	1.282
20	1.340	2.544	0.980	1.014*	1.400	1.371	1.173
21	1.421	2.612	0.987	1.172	1.390	1.519	1.287
22	1.313	2.674	0.954	1.320	1.519	1.664	1.411
23	1.416	2.814	0.807	1.401	1.498	1.734	1.524
24	1.437	2.758	0.889	1.454	1.486	1.788	1.456
25	1.474	2.852	0.921	1.413	1.496	1.710	1.403
26	1.535	2.733	0.979	1.455	1.597	1.728	1.517
27	1.608	2.675	0.957	1.528	1.597	1.770	1.661
28	1.675	2.629	0.967	1.453	1.508	1.699	1.744
29	1.784	2.659	1.010	1.432	1.558	1.695	1.567
30	1.902	2.851	1.123	1.433	1.615	1.737	1.561
31	1.865	2.869	1.107	1.322	1.555	1.676	1.526
32	1.741	2.769	1.070	1.447	1.551	1.773	1.484
33	1.707	2.795	1.085	1.522	1.557	1.799	1.520
34	1.869	2.450	1.074	1.517	1.423	1.704	1.589
35	1.794	1.878	1.097	1.541	1.443	1.689	1.592
36	1.789	1.789	1.060	1.429	1.282	1.480	1.359
37	1.810	1.783	1.180	1.632	1.306	1.623	1.461
38	1.703	1.323	1.242	1.493	1.280	1.487	1.303
39	1.646	1.397	1.100	1.535	1.273	1.460	1.160
40	1.497	1.495	1.219	1.490	1.057*	1.349	1.163
41	1.365	1.389	1.179	1.525	1.065	1.386	1.189
42	1.513	1.309*	1.112	1.588	1.132	1.539	1.254
43	1.435	1.509	1.129	1.524	1.100	1.504	1.256
44	1.316	1.373	1.109	1.494	1.182	1.497	1.358
45	1.413	1.507	1.198	1.628	1.365	1.657	1.489
46	1.510	1.677	1.300	1.610	[illegible]	[illegible]	1.407
47	1.604	1.928	1.019	1.264	1.073	1.223*	1.095
48	1.916	1.469	1.025	1.385	1.168	1.372	1.097
49	2.104	1.700	[illegible]	1.570	1.304	1.568	1.184
50	2.006	1.713	0.624*	1.529	1.235	1.526	1.020*

Table 2. Values of S_k^2 of annual precipitation at seven stations.

K	DODGE C.	VICKSB.	MEMPHIS	CAIRO	MADISON	PITTSB.	LYNCHB.
01	23.592	17.841	15.928	12.692	17.177	13.620	17.290
02	14.503	11.203	9.297	6.746	9.393	7.375	11.203
03	10.156	8.312	7.040	4.523	7.195	4.898	7.321
04	8.631	6.722	5.914	3.450	6.135	3.816	5.945
05	7.956	6.184	5.532	2.784	5.873	3.234	5.278
06	7.248	5.460	4.217	2.299	5.611	2.755	4.300
07	6.292	5.016	3.826	2.080	5.477	2.583	4.214
08	6.218	4.792	3.620	1.865	5.563	2.278	3.775
09	6.231	4.469	3.445	1.584	5.540	2.206	3.669
10	6.230	4.267	3.320	1.476	5.355	1.992	3.524
11	6.211	3.930	3.064	1.214	5.184	1.827	3.367
12	6.158	3.586	2.863	0.995	4.904	1.769	3.150
13	6.179	3.400	2.712	0.837	4.172	1.808	3.004
14	6.191	3.291	2.637	0.800	4.048	1.849	3.056
15	5.965	3.082	2.507	0.812	3.384	1.821	3.003
16	6.025	3.230	2.444	0.727	3.301	1.405	3.089
17	5.723	3.114	2.256	0.758	3.092	1.318	2.976
18	5.886	2.960	2.315	0.722*	2.935	1.339	2.594
19	5.865	3.038	2.259	0.793	2.534	1.038	2.508
20	5.824	3.010	2.294	0.830	2.517	0.990	2.558
21	5.713	3.037	2.244	0.948	2.478	1.020	2.594
22	5.668	3.069	1.923	0.857	2.410	1.061	2.453
23	5.580	3.200	1.835	0.915	2.374	0.995	2.475
24	5.322	3.296	1.808	0.965	2.298	0.977	2.403
25	4.998	3.252	1.838	0.918	2.307	0.936	2.264
26	4.893	3.064	1.872	0.936	2.284	0.945	2.144
27	4.991	3.050	1.837	0.837	2.098	0.934	1.873
28	5.255	3.002	1.882	0.984	1.964	1.100	1.794
29	4.960	2.817	1.844	1.055	2.029	1.127	1.863
30	5.070	2.789	1.750	1.140	1.959	0.773	1.315
31	5.087	2.712	1.841	1.122	2.026	0.819	1.217
32	4.408	2.691	1.923	1.308	1.997	0.878	1.210
33	4.557	2.760	1.952	1.439	[illegible]	[illegible]	1.151
34	4.408	2.919	2.002	1.693	1.960	1.038	1.046
35	3.697	3.031	1.776	1.604	1.837	1.123	1.059
36	3.820	2.955	1.843	1.744	1.783	1.080	0.751*
37	3.320	3.038	1.977	1.753	1.797	1.080	0.895
38	3.077	2.988	2.061	1.835	1.799	1.070	1.018
39	2.689	3.071	2.039	1.418	1.936	0.954	0.986
40	2.828	2.786	1.912	1.486	1.927	0.694*	0.981
41	2.681	2.745	2.027	1.667	1.513	0.757	0.909
42	2.768	2.612	2.095	1.584	1.245	0.845	1.012
43	2.876	2.536	2.074	1.744	1.158	0.917	1.041
44	1.365*	2.725	1.769	1.637	1.239	0.999	1.109
45	1.474	2.703	1.848	1.619	1.157	1.241	0.936
46	1.560	2.815	1.920	1.779	1.278	1.181	0.985
47	1.816	1.475	2.020	1.778	0.969*	1.327	0.975
48	1.597	1.357*	1.703	1.877	1.012	1.217	1.033
49	1.538	1.399	1.350	2.086	1.045	1.272	0.835
50	1.679	1.418	1.303*	2.056	1.230	1.331	0.931

k-element mean, not including it, is normally distributed with mean 0 and variance $s^2 + s^2/k$, as shown previously (SR 1). Hence s_k^2 should decrease as $(1 + 1/k)\ s^2$.

Departures from such behavior appear on all the figures. Minor fluctuations about the theoretical line could represent sampling errors: for two samples of 100 random normal numbers s_k^2 deviated somewhat from the appropriate line (SR 1, Figs. 8-11), but for 1,000 such numbers s_k^2 followed the line quite closely (SR 1, Fig. 13). Some of the large swings may be the results of changes in mean or in variance: s_k^2 increases with k if the mean changes, decreases if the variance changes (SR 1).

Thus a shift in mean is suggested for the annual temperatures (Fig. 8B) at all stations except possibly Vicksburg, as suggested for some stations in the actual data (Fig. 8A), graphed. as departures from the mean. A shift in mean seems likely at Dodge City in February (Fig. 1A), and possibly at other stations in other months. In annual precipitation (Fig. 25B), Cairo shows great similarity to the most strongly biased synthetic case (SR 1, curve 4 of Figs. 8 and 10), with nearby Memphis somewhat less extreme; Lynchburg also has the same tendency. In the monthly precipitation curves, shifts in mean are suggested for:

Vicksburg, Fig. 19D, October and November
Memphis, Fig. 20C, January
Cairo, Fig. 21C, January
Madison, Fig. 22D, September
Lynchburg, Fig. 24D, August

Changes in variance, indicated by a plunging s_k^2 curve, are suggested by the curve for yearly precipitation at Madison (Fig. 24) and traces for:

Station	Temperature Fig.	Month	Precipitation Fig.	Month
Dodge City	1	Mar.	18	June., Sep.
Vicksburg			19	Oct., Dec.
Memphis	3	Jan., Dec.	20	Oct.
Cairo	4	Dec.	21	Oct.
Madison	5	Jan., Feb., Dec.	22	Jul.
Pittsburgh	6	Nov.	23	Apr.
Lynchburg			24	Sep., Oct.

Such shifts in mean or in variance, if actually the causes of the steep climbs or descents of the s_k^2 curves, do not come from changes in station location or observing practice. If they did, curves for consecutive months at the same station would be similar. But little coherence is shown by curves for successive months.

However, the s_k^2 curves for the same month at nearby stations often show marked similarities. Memphis and Cairo have already been noted as showing possible shifts in the January mean temperature, and variance shifts in December temperature and October precipitation. In fact, at these two stations, 150 miles apart along the Mississippi River, all corresponding s_k^2 curves for temperature are quite similar (Figs. 3 and 4), but the precipitation curves (Figs. 19 and 20) show no close similarities, although both have the same gross features in October.

This behavior agrees with the general climatologic principal that temperature has somewhat greater regional coherence than does precipitation. For each, the correlation at 150-mile separation is greater than the year-to-year correlation at any other place; for none of the seven stations is the serial correlation of either element in any month significantly different from zero, at any lag.

3. Comparisons

While the erratic behavior of S_k^2, as k increases, poses interesting theoretical climatologic questions, it also raises an important practical problem. For each year at each of the seven stations, and for all of them together, what number (k) of antecedent years would have given a mean closest to that year's temperature and precipitation, for each month? A simple average of all the k^* values might not be appropriate, because many S_k^2 curves had such broad minima that S_{k*}^2 was only fractionally less than values of S_k^2 for adjacent values of k.

In hopes of solving this problem, values of k^* and all other values of k for which S_k^2 was not more than 5 % greater than S_{k*}^2 were graphed. All annual values were compared on rectangular diagrams, and monthly values at each place on polar diagrams, separately for temperature (Fig. 9) and for precipitation (Fig. 25). On each diagram, k^* is indicated by a dashed line, and single solid lines or shaded areas indicate those values of k for which $S_k^2 \leq 1.05\ S_{k*}^2$.

The only useful conclusion derived from many hours of study of these graphs, and of the S_k^2 curves, is that almost any value of k from 10 to 40 years would, on balance, give about the same predictive accuracy for these seven stations for the period studied. This tentative conclusion, or working hypothesis, will be examined, in later reports, with respect to other climatic elements and stations in other parts of the world, and for different periods.

First, however, comes the question of whether S_k^2 is an inherently unstable criterion. Perhaps the mean absolute error, Q_k, behaves better, and can more readily define the optimum period of record on which a climatic average or normal should be based, if it is to be used primarily for prediction (which is really the primary use to which normals are put). Perhaps, also, a k-year <u>median</u> is a more suitable predictor, as measured by its mean absolute error, D_k , than is the k-year mean measured by either S_k^2 or Q_k .

Both Q_k and D_k were computed for annual and monthly temperature and precipitation at the same seven stations. Resulting values are shown in Figs. 10-17 and 27-34. These figures bear the same lines as the previous figures, showing the expected behavior of S_k^2 for independent numbers from a normal population. This is not the behavior expected of Q_k or D_k , which has as yet been established in theory. However, on computations with 1000 random normal variates, Slusser (SR 3, pp. 51-53) found that both Q_k and D_k reach their asymptotes much more quickly than does S_k^2 ; neither decreased appreciably after k exceeded 20 (Figs. 57 and 59, curves "O"). Hence in Figs. 10-17 and 27-34, the curves for Q_k and D_k would be expected to be somewhat flatter than the theoretical curves for S_k^2 , shown on the diagrams.

To eliminate ambiguity in defining the median, only odd values of k were used for D_k . Since Q_k , being also a mean absolute difference, is more suitable than S_k^2 for comparison with D_k , the graphs for Q_k were drawn for only the odd values of k , with the magnitude of Q_k for the even values of k indicated by dots, connected to the line.

No essential differences could be found between the behaviors of D_k , Q_k , and S_k^2 . In fact, for the same data the three curves are quite similar, rising, falling, jumping or steadying at the same values of k . The shifts in mean or in variance suggested by the S_k^2 behavior are not the consequences of taking squared differences from the mean, but are caused by inherent characteristics of the climatic data.

In almost two-thirds of the station-months, the smallest mean absolute difference from the median, D_{k*} , was less than the smallest mean absolute difference from the mean, Q_{k*} . In most cases, the number of years, $k*$, was the same for the median as for the mean. But the median was somewhat closer, on the average, to the next year's value. Because of the similarity of behavior, no detailed analysis was made of the $k*$ values for Q_k or D_k . But the working hypothesis was expanded to suggest that the median of 10 to 40 antecedent years may be a better predictor than the mean for the same period, whose precise length seems immaterial. This hypothesis will be investigated further in subsequent reports.

4. Figures

All the properties of the monthly and annual temperature and precipitation at the seven U.S. stations are shown in 104 diagrams, grouped into 17 figures. Temperature diagrams are given first, followed by precipitation diagrams in exactly the same order. The entire arrangement is planned for easy intercomparisons.

In each series, a pair of monthly S_k^2 diagrams for each station is accompanied by a bar diagram of departures from normal. Annual values for all seven stations are shown as departures, and as S_k^2 curves. Behavior of $k*$ is then summarized on circular diagrams mounted on a map. Monthly graphs of Q_k and D_k for each station come next, followed by annual Q_k and D_k diagrams for all stations.

Figures exhibiting the behavior of temperature series at seven U.S. stations

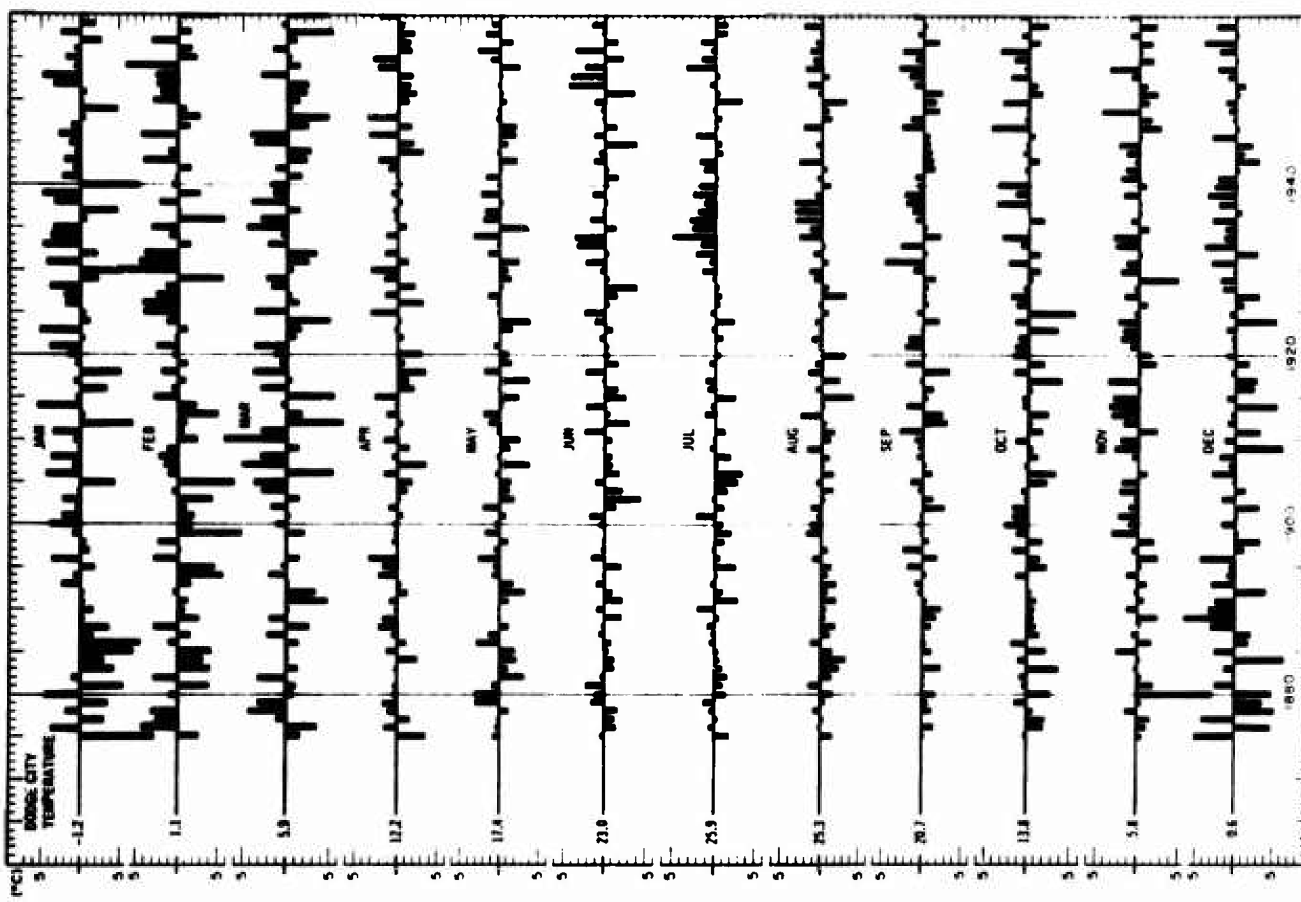
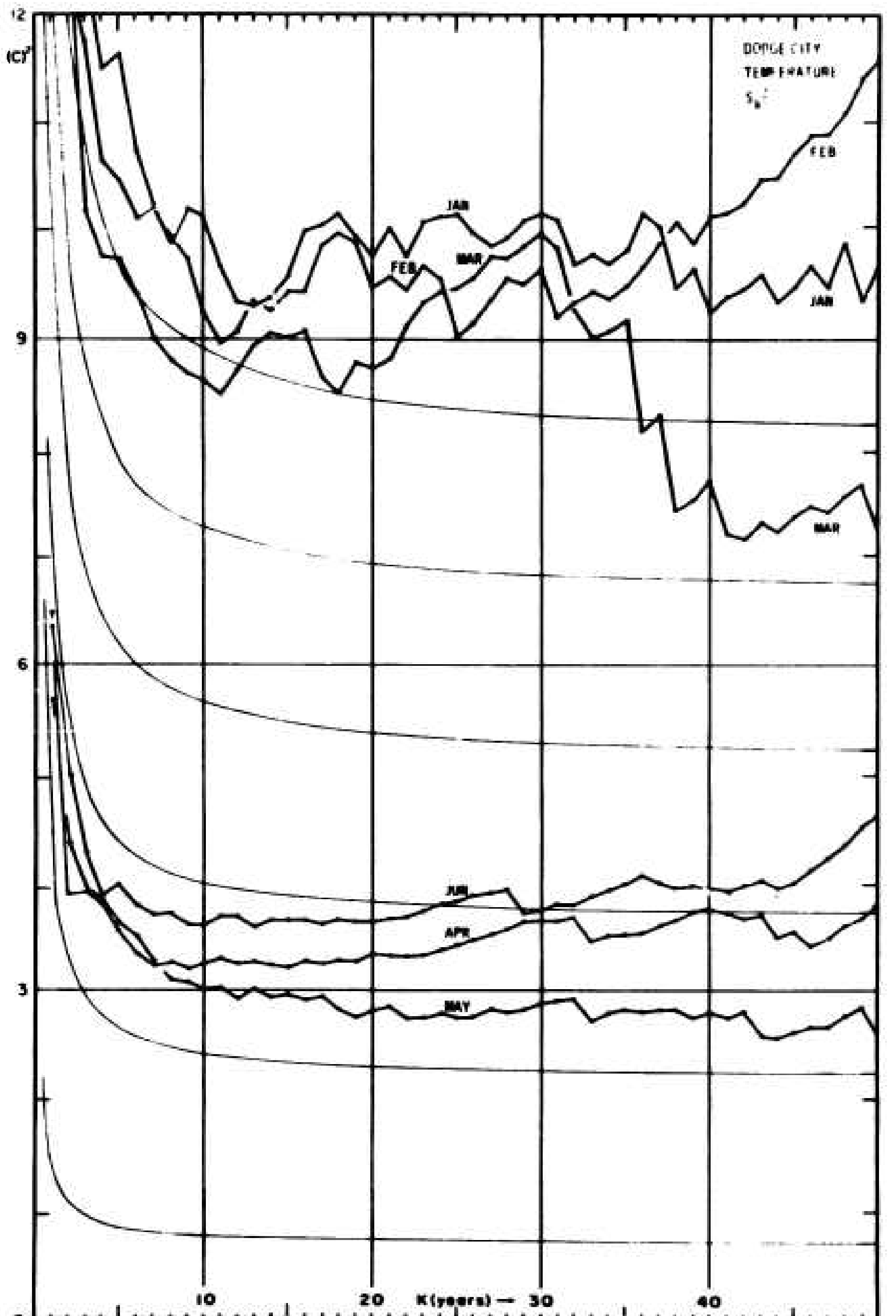
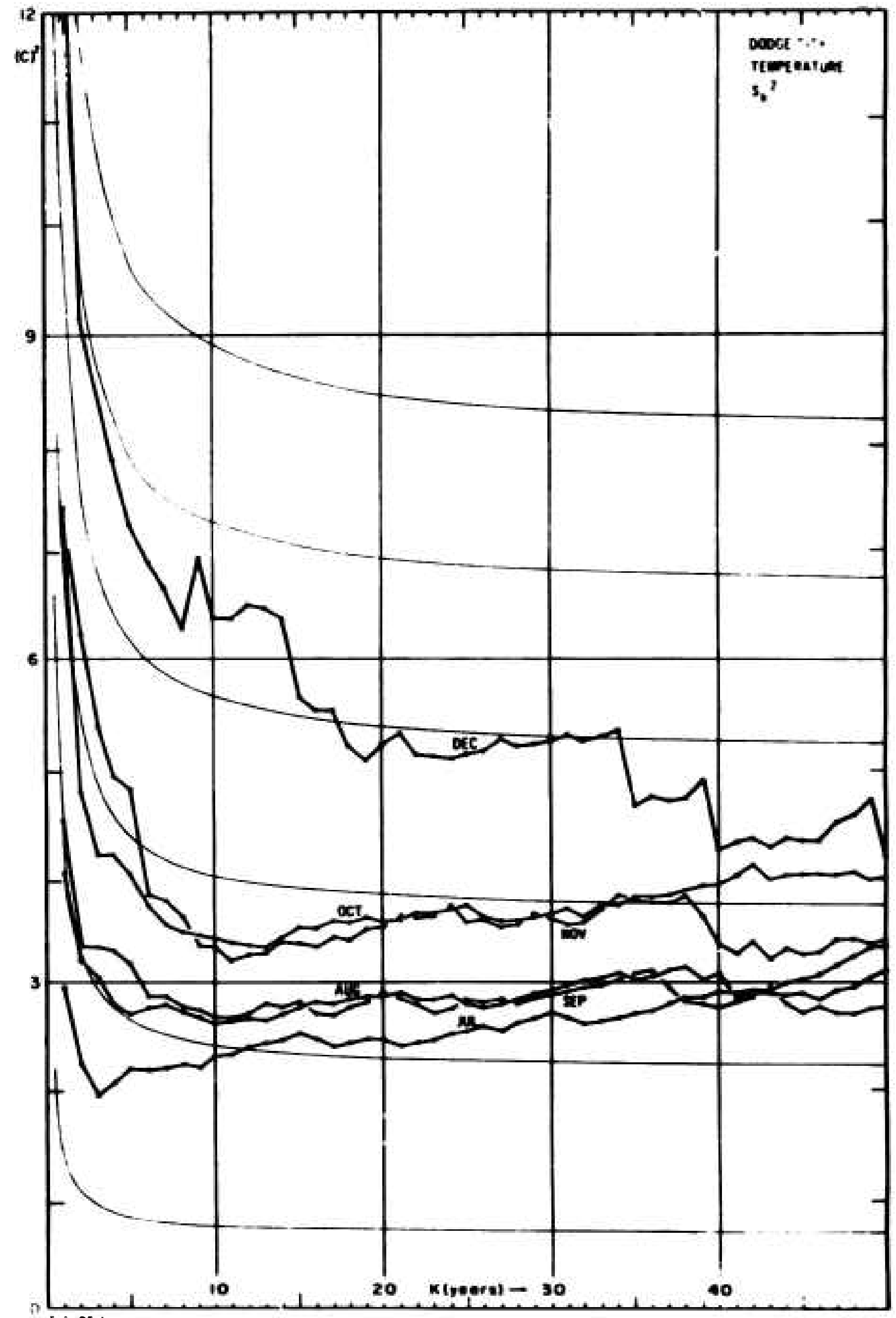

DODGE CITY TEMPERATURE
(°C)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1880
1900
1920
1940

FIGURE 1A


DODGE CITY
TEMPERATURE
12
9
6
3
0
(C)²
10
20
K(years) — 30
40
JAN
FEB
MAR
JUN
APR
MAY
FIGURE 1B


TEMPERATURE
12
9
6
3
(C)²
10
20
K(years) — 30
40
DEC
OCT
NOV
AUG
SEP
JUL

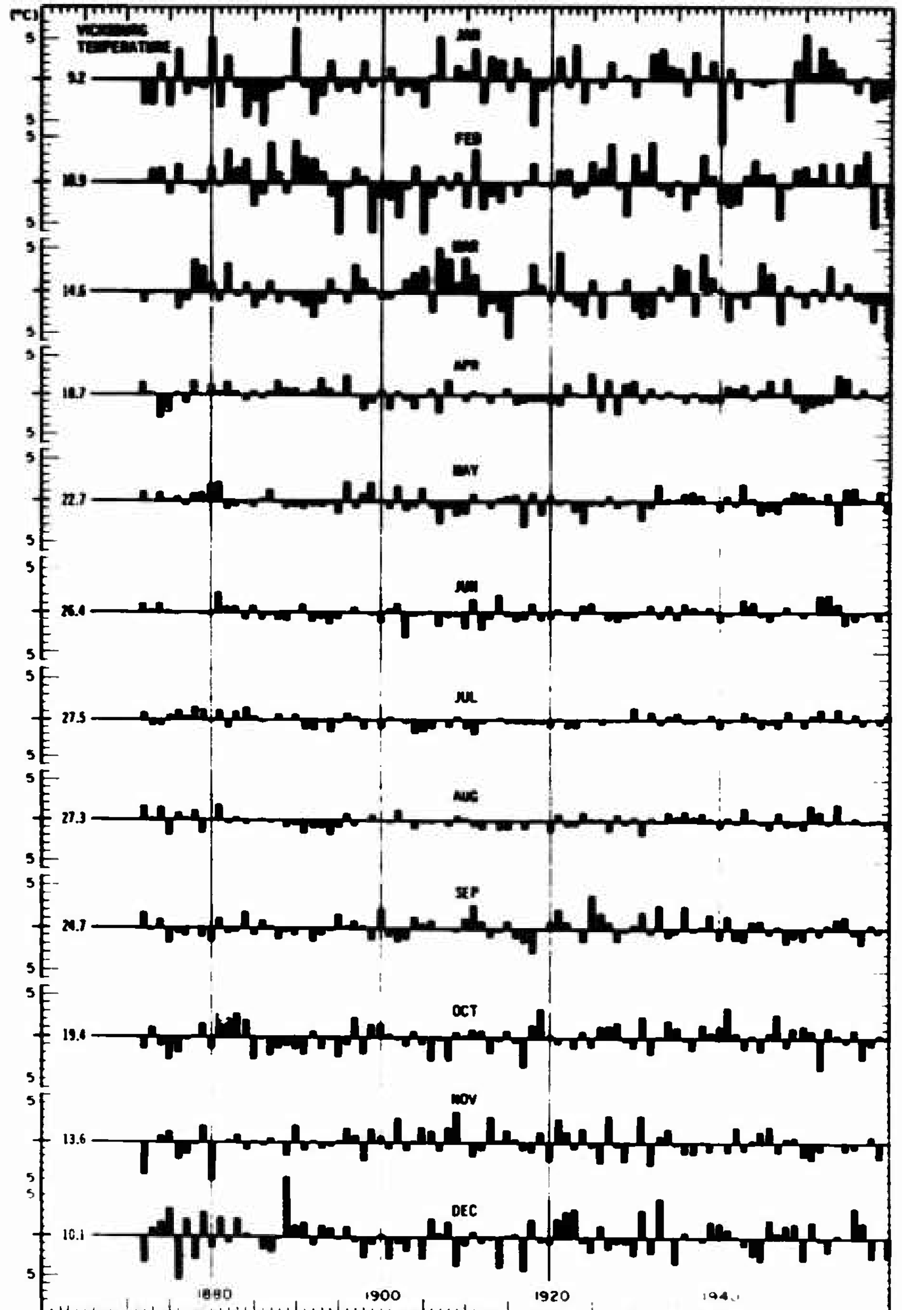
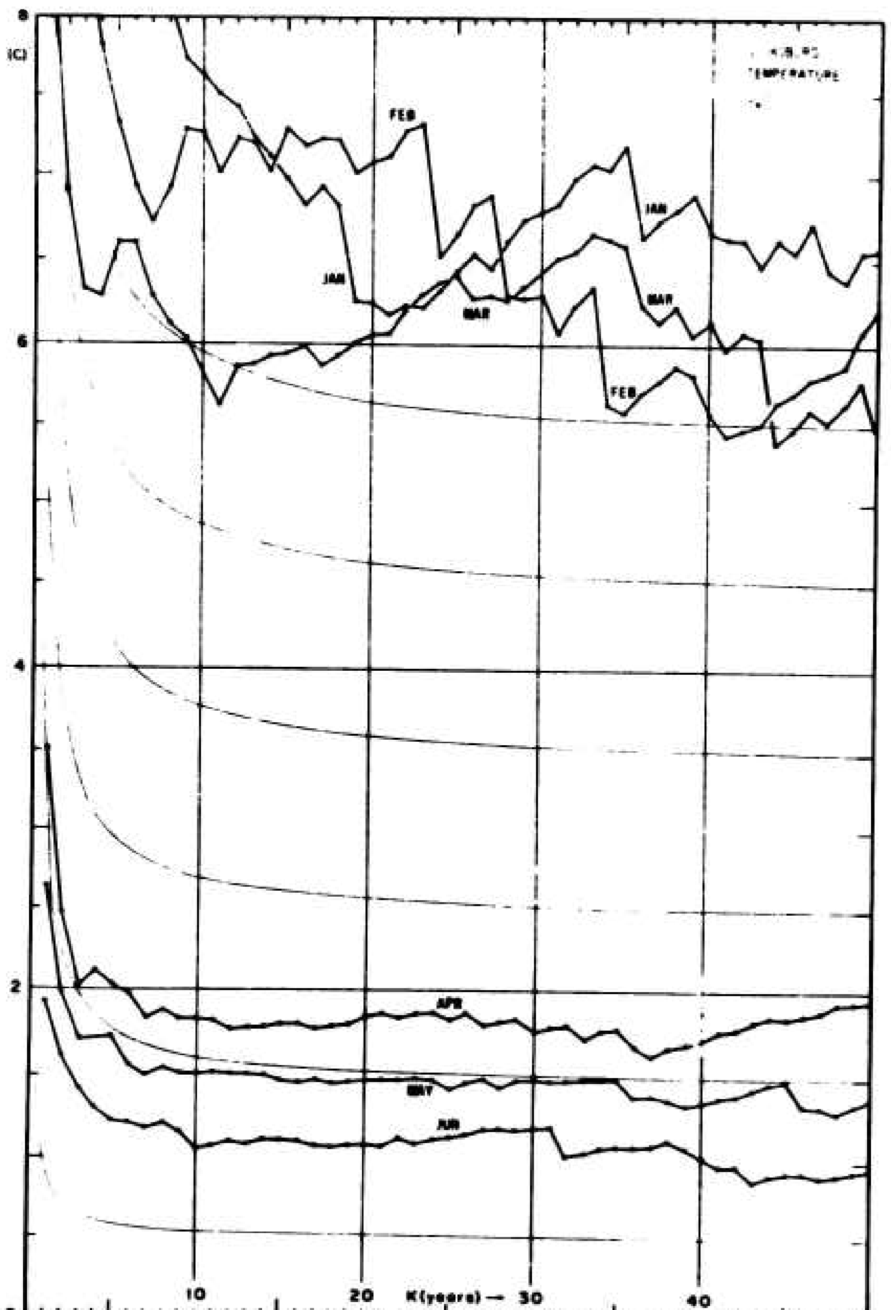
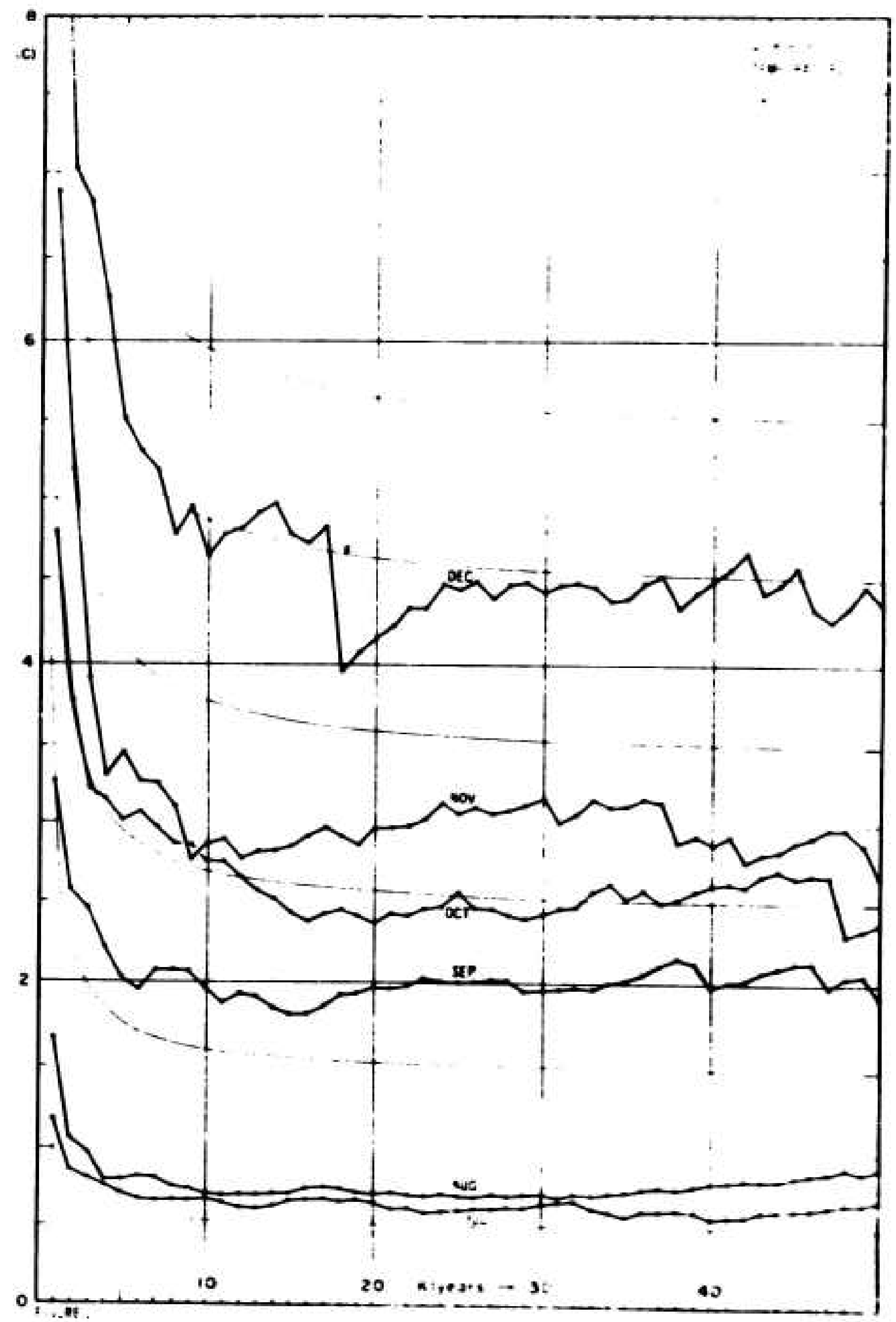

(°C)
VICKSBURG TEMPERATURE
JAN
9.2
FEB
10.9
MAR
14.6
APR
18.7
MAY
22.7
JUN
26.4
JUL
27.5
AUG
27.3
SEP
24.7
OCT
19.4
NOV
13.6
DEC
10.1
1880
1900
1920

FIGURE 2A



(C)
TEMPERATURE
FEB
JAN
MAR
APR
MAY
JUN
8
6
4
2
0
10
20
K(years) → 30
40

FIGURE 2B



8
(C)
6
4
2
0
DEC
NOV
OCT
SEP
AUG
10
20
40

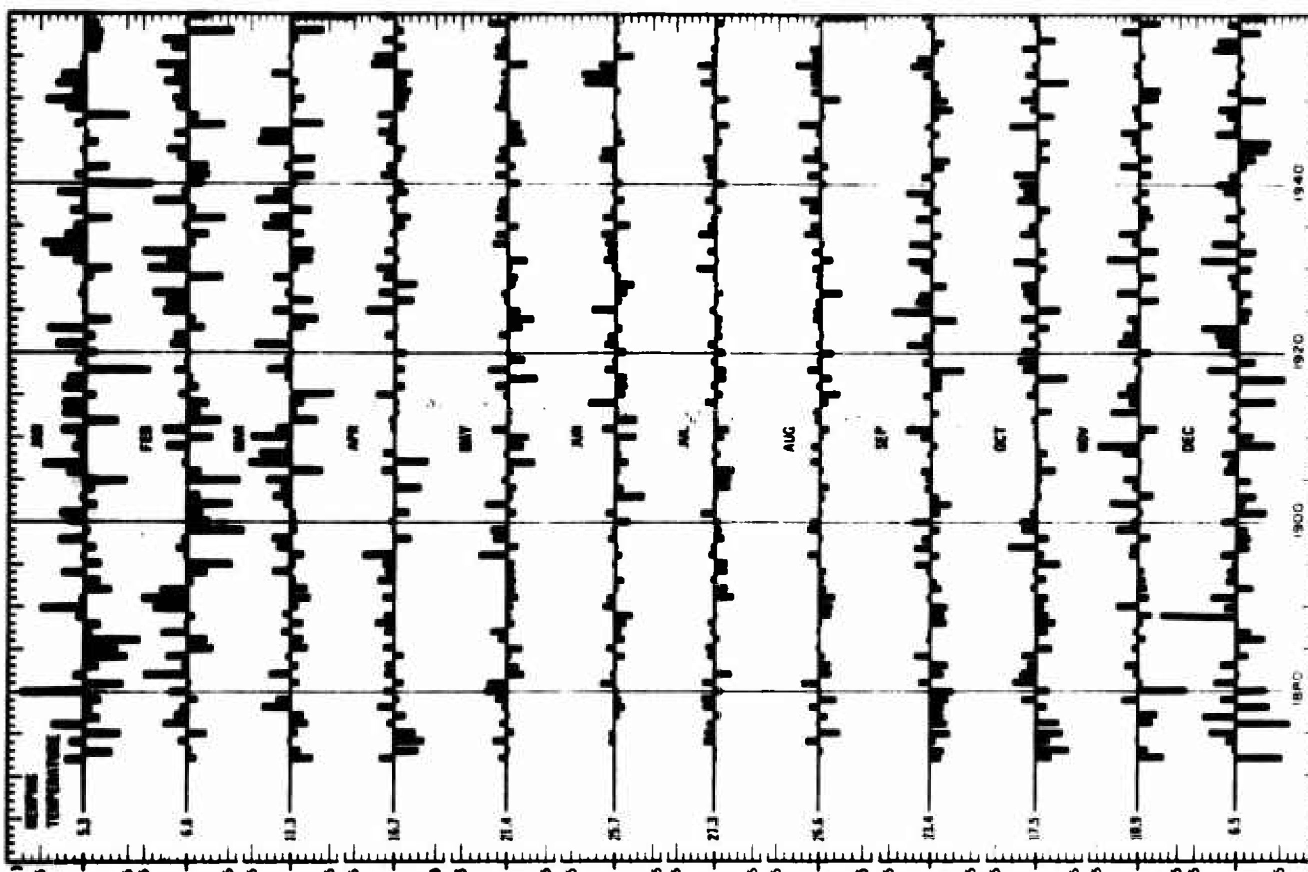


FIGURE 3A

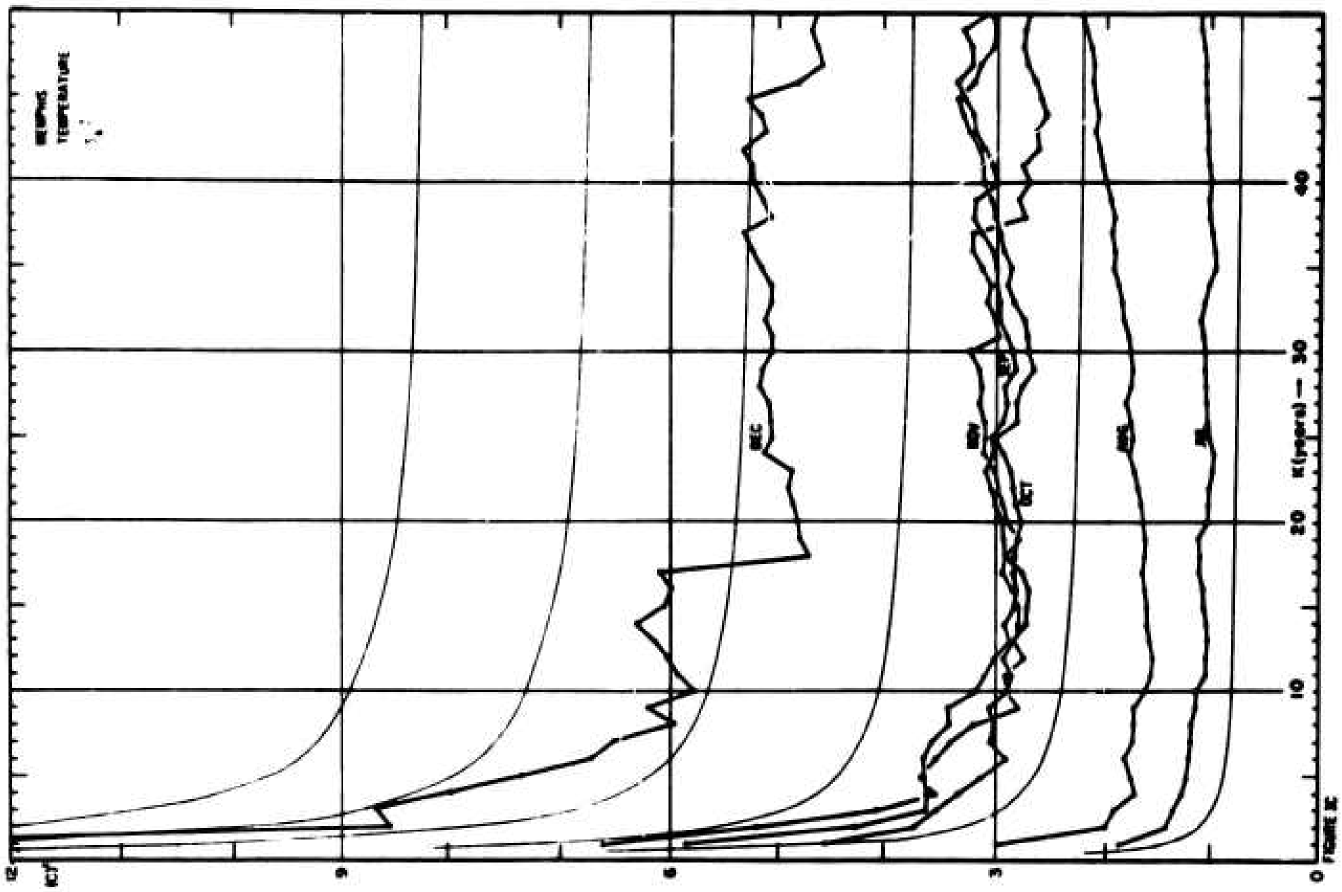


FIGURE 3C

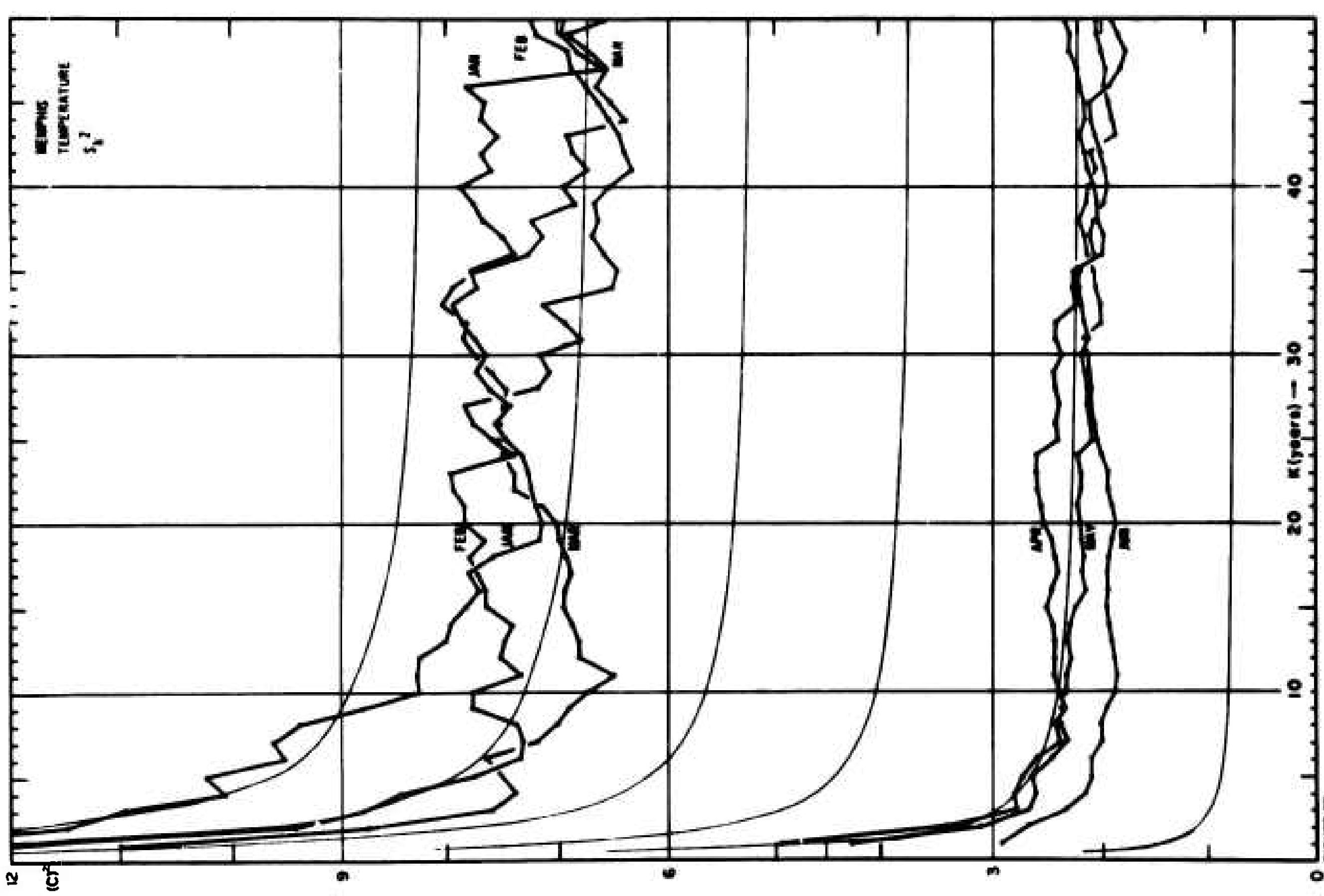
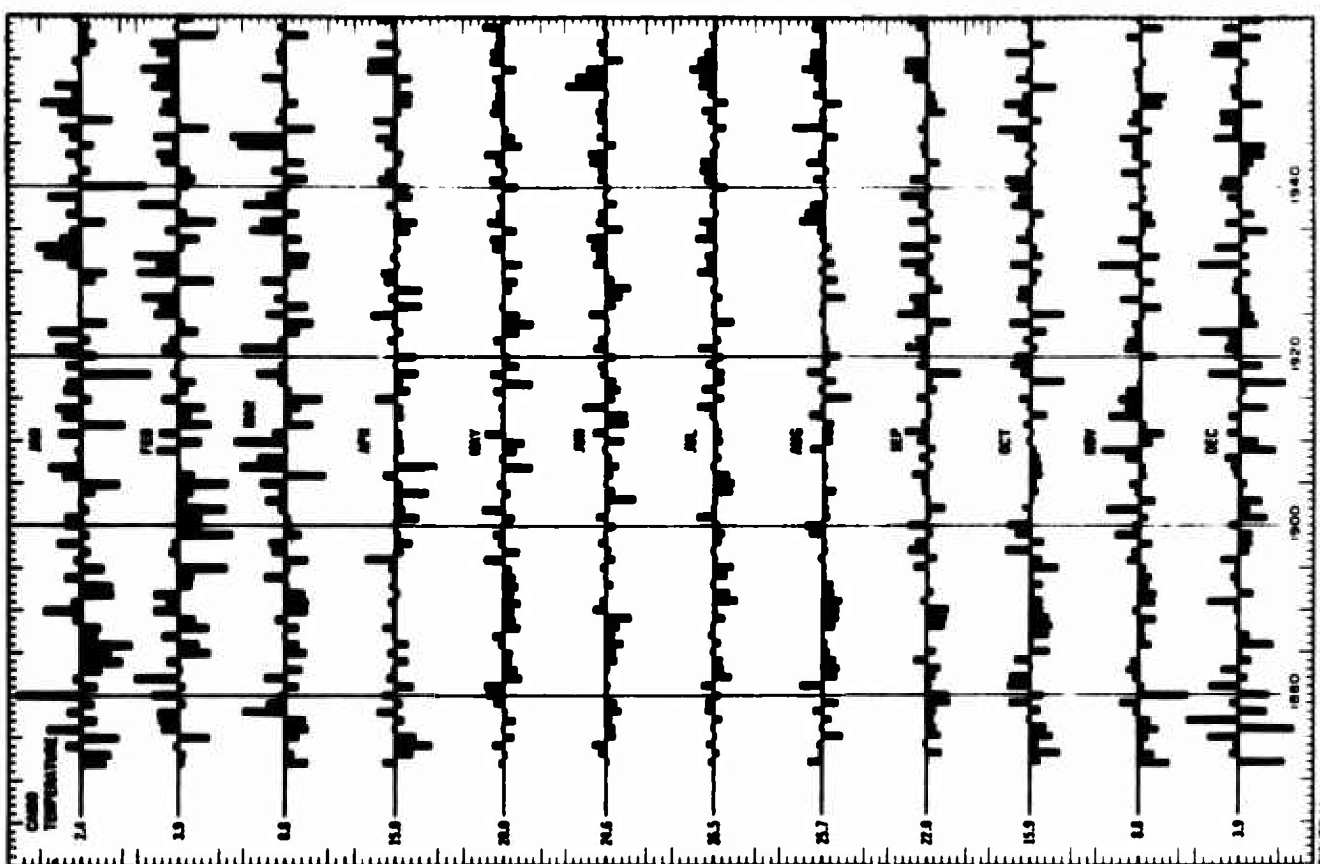
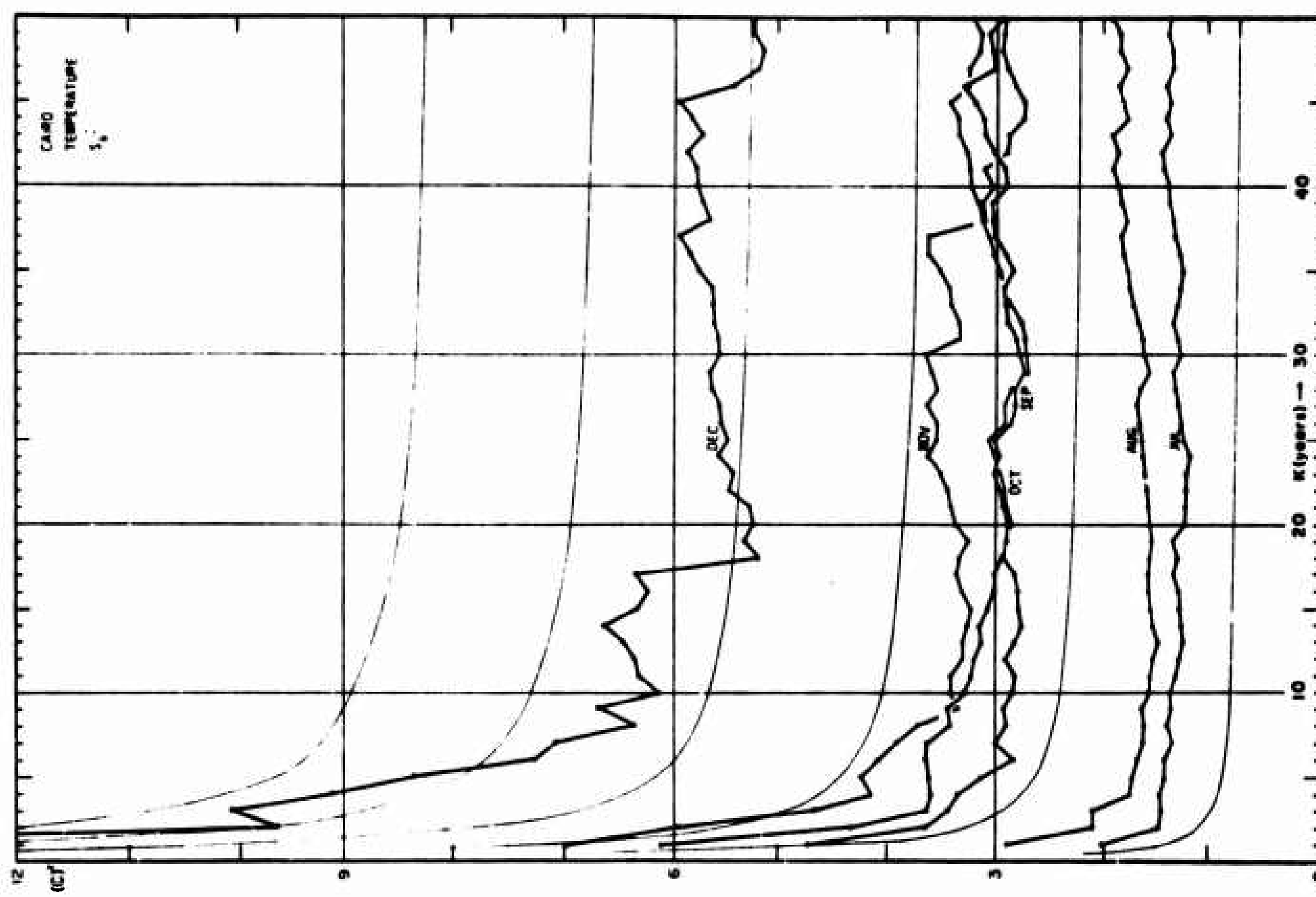
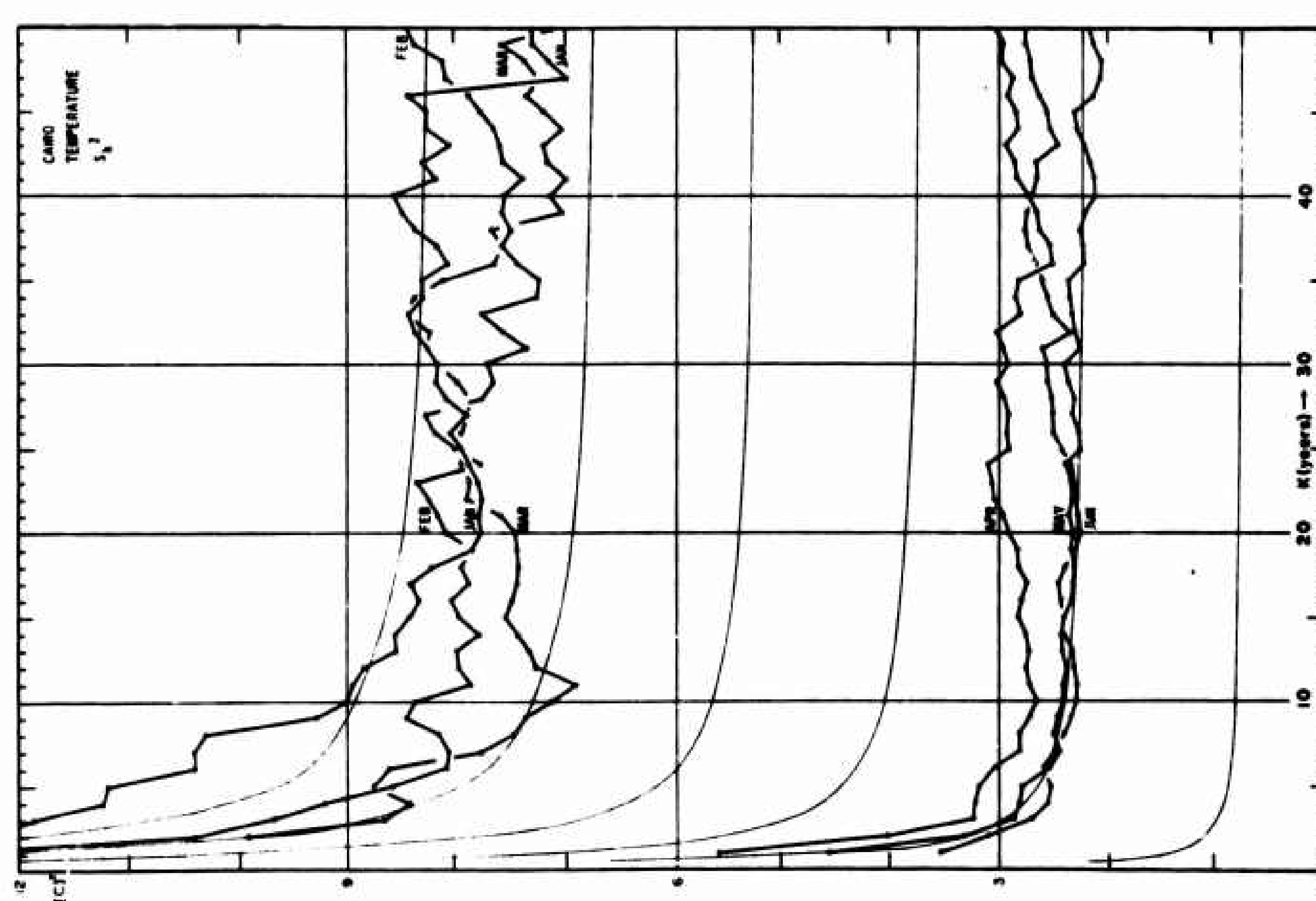


FIGURE 3B




CAIRO
TEMPERATURE
K(years) —
DEC
NOV
OCT
SEP
AUG
JUL
0
3
6
9
12
(C)²
10
20
30
40
FIGURE 4C


CAIRO
TEMPERATURE
K(years) —
FEB
JAN
MAR
APR
MAY
0
3
6
9
12
(C)²
10
20
30
40
FIGURE 4B

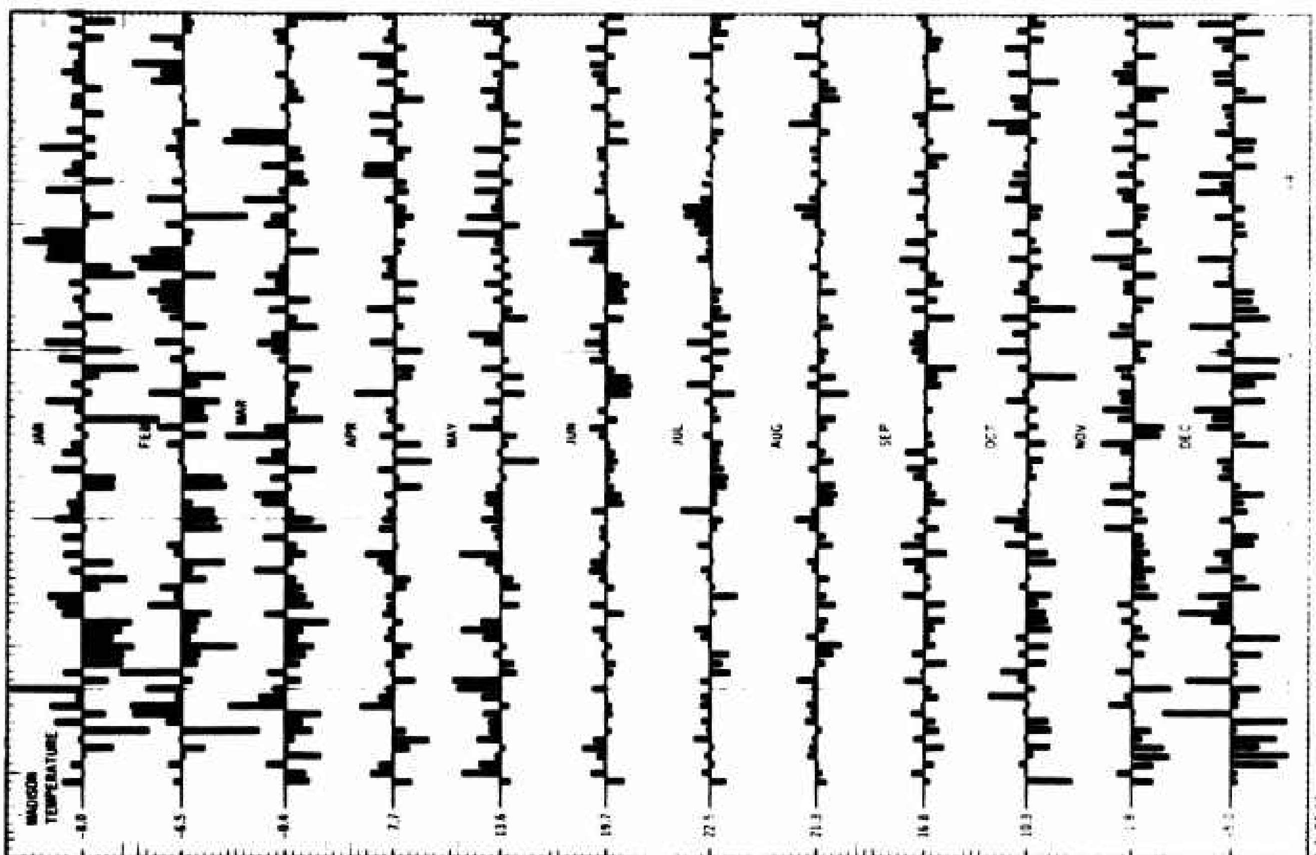

(°C)
MADISON TEMPERATURE
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 5A

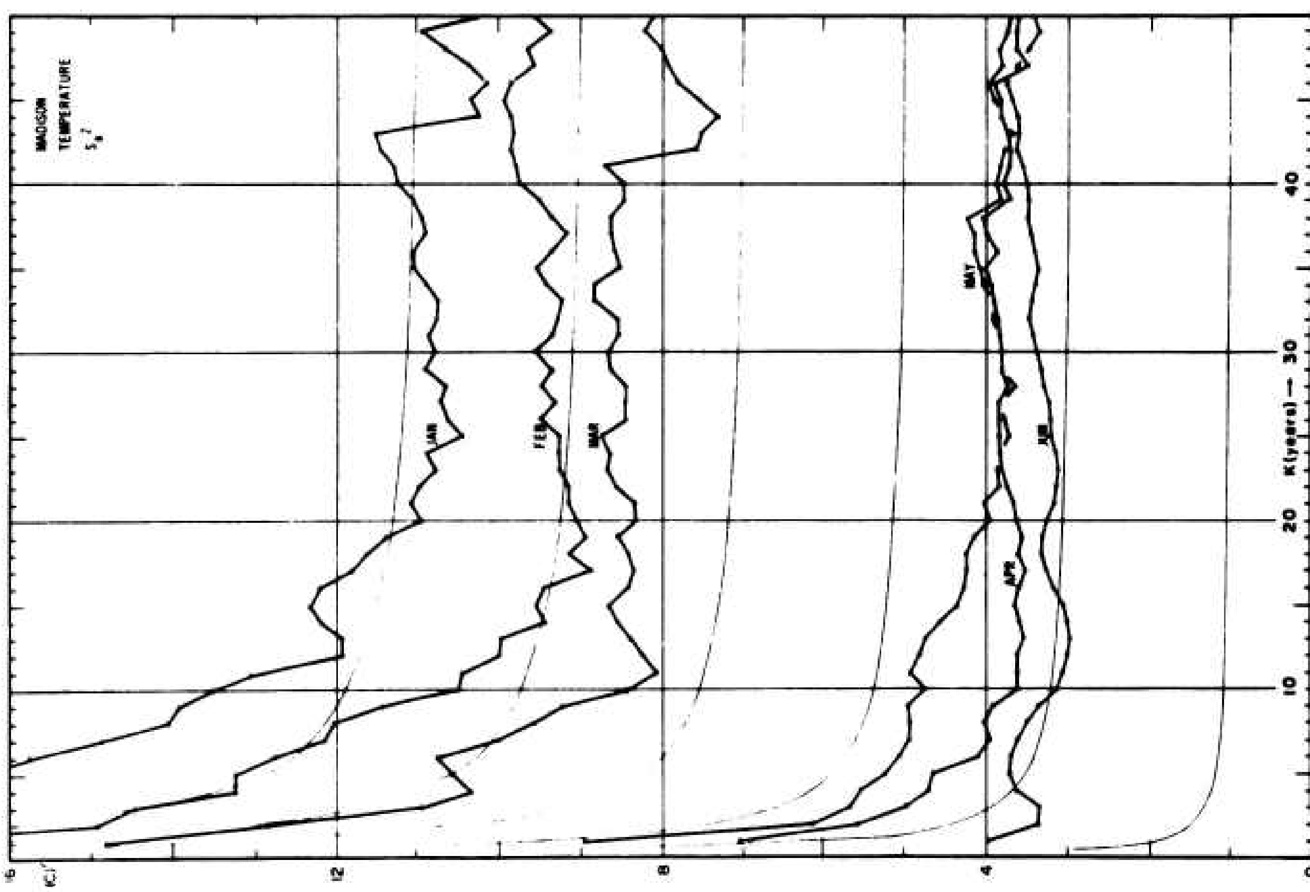


FIGURE 5B

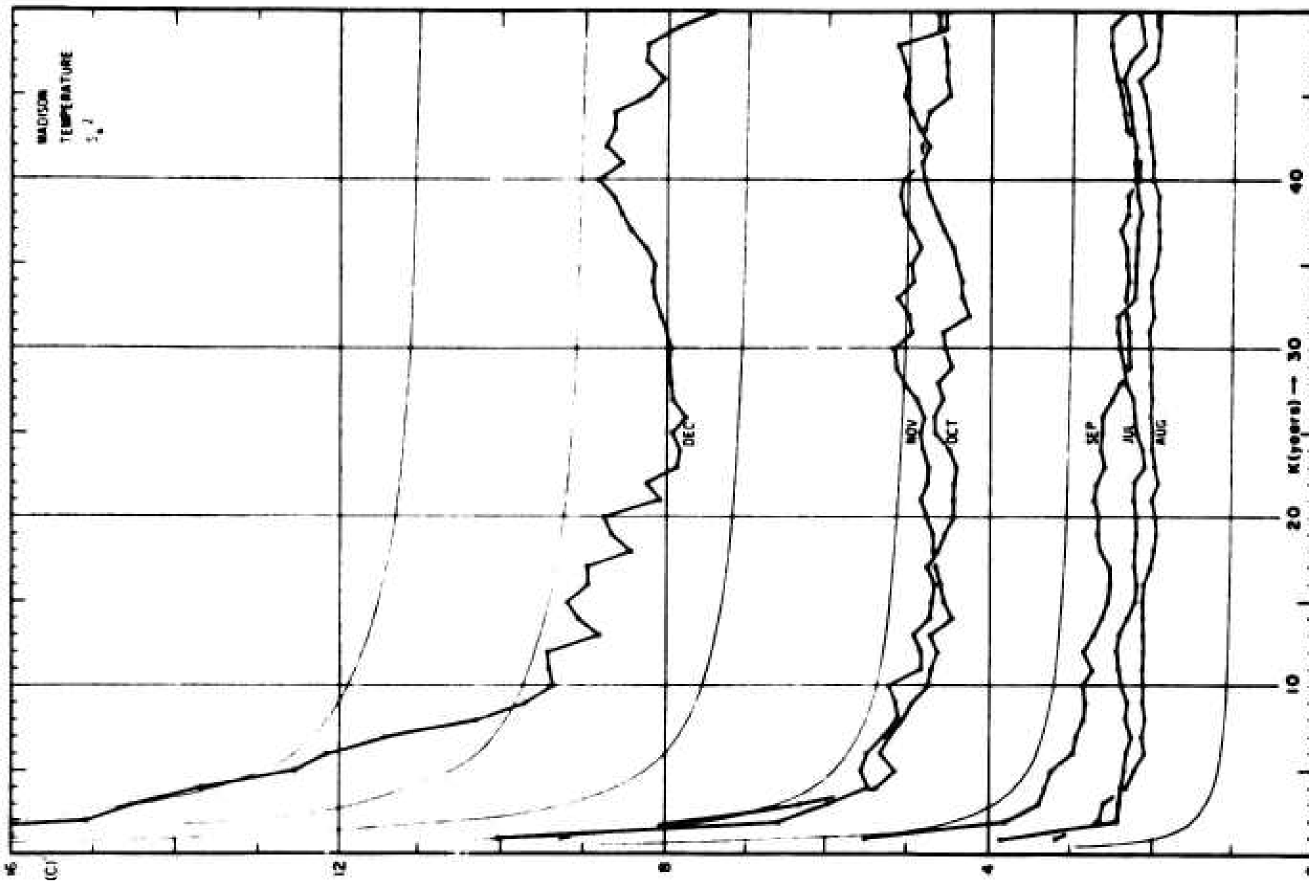


FIGURE 5C

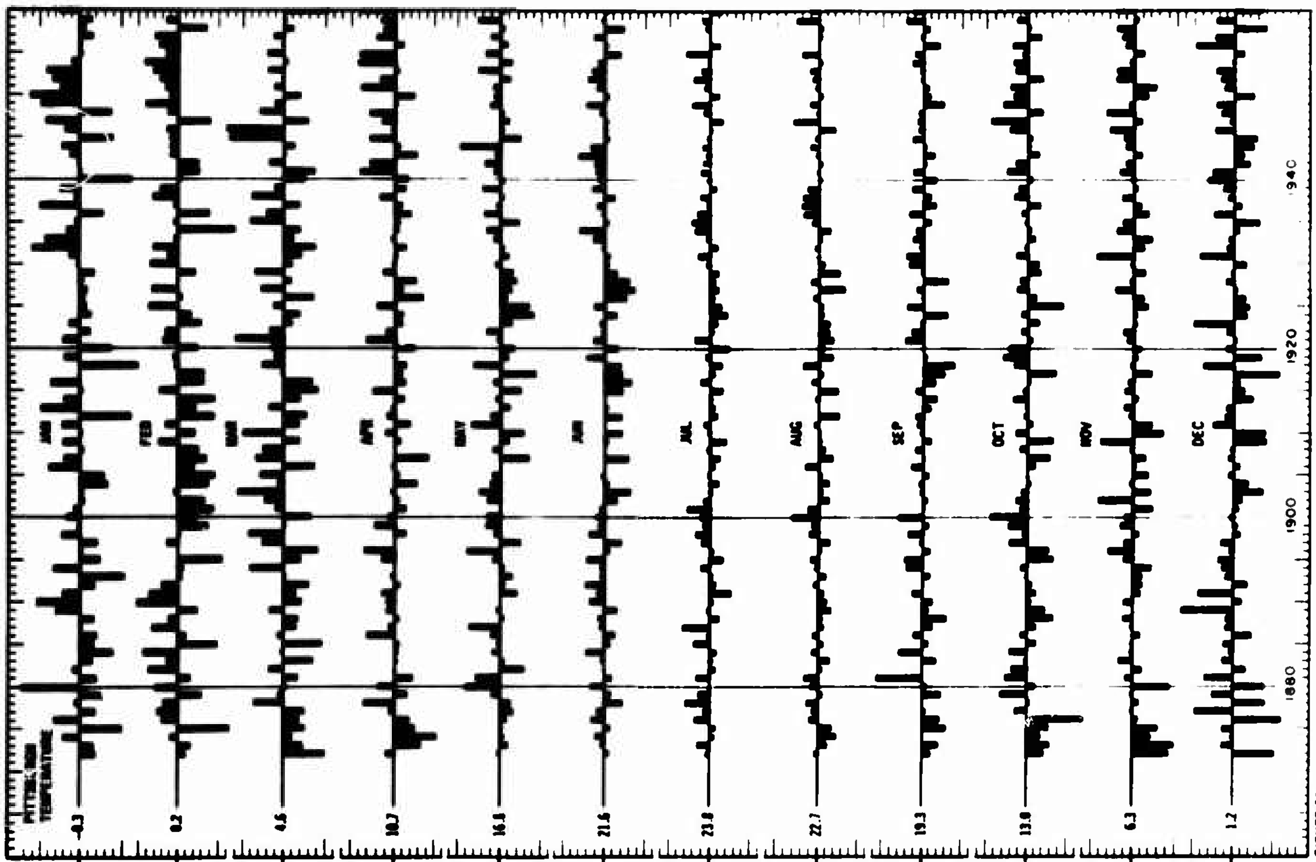
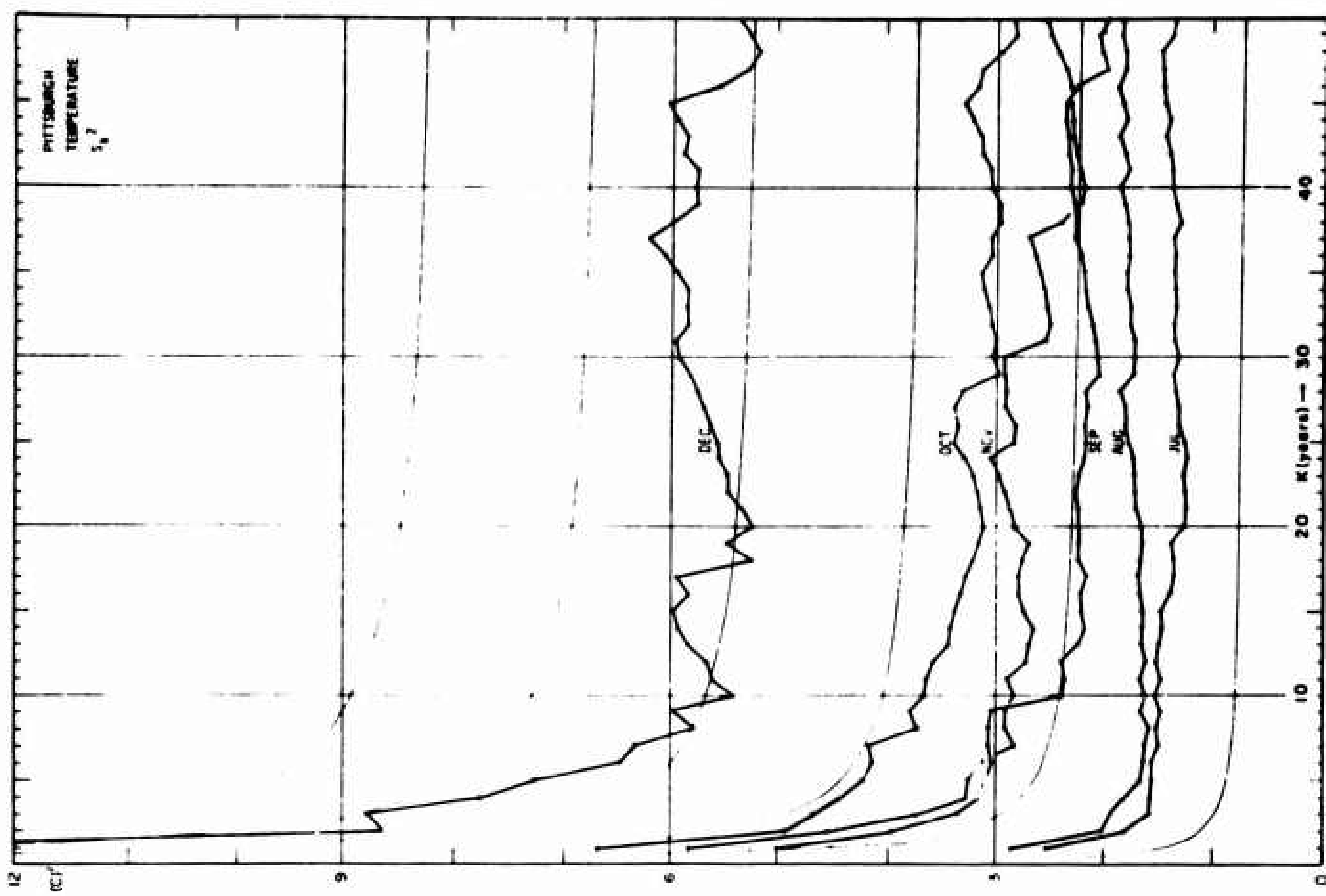

(°C)
PITTSBURGH TEMPERATURE
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
-0.3
0.2
4.6
10.7
21.6
23.8
22.7
19.3
6.3
1.2
1880
1900
1920
1940

FIGURE 6A


PITTSBURGH
TEMPERATURE
DEC
OCT
NOV
SEP
AUG
JUL
K(years) — 30

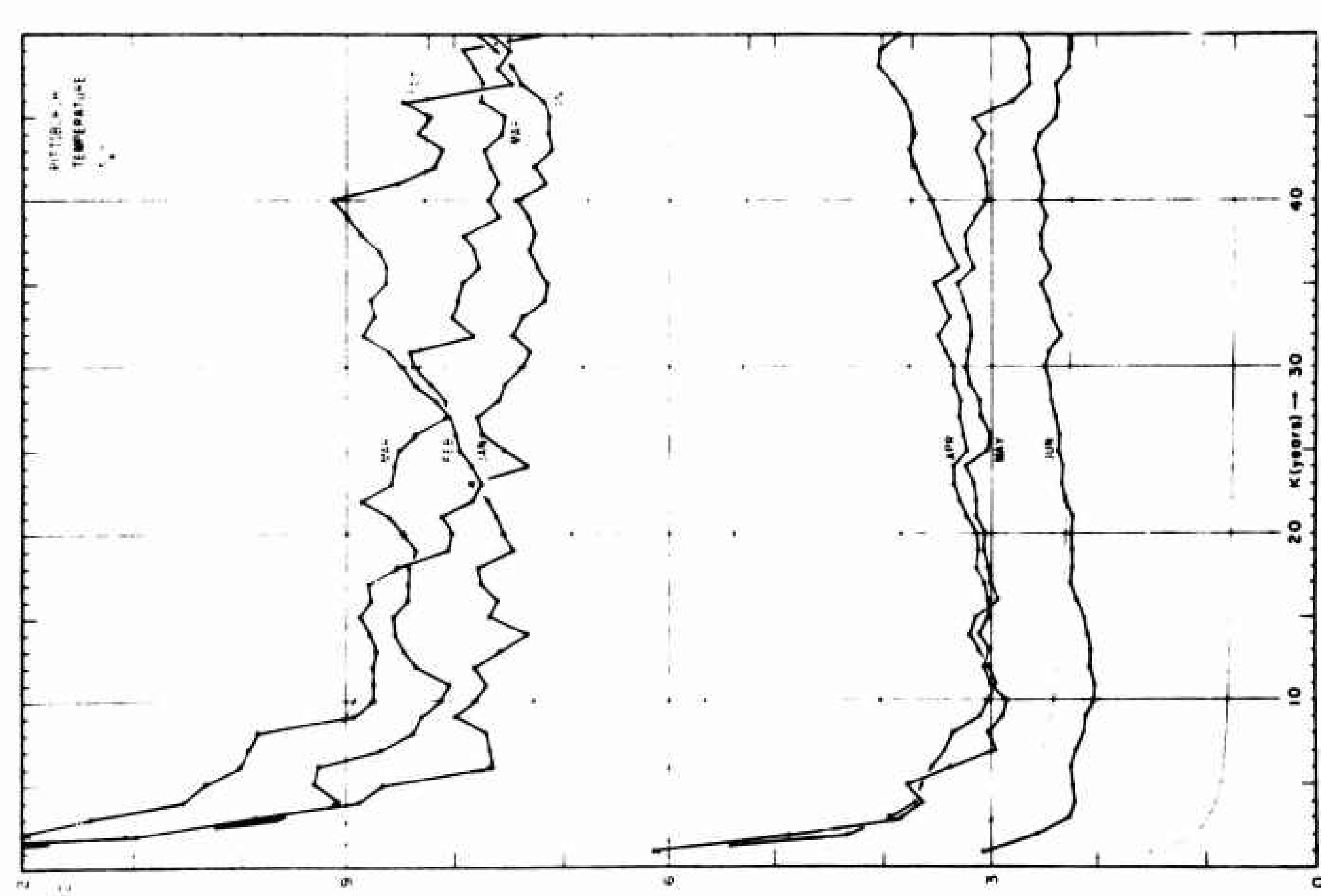
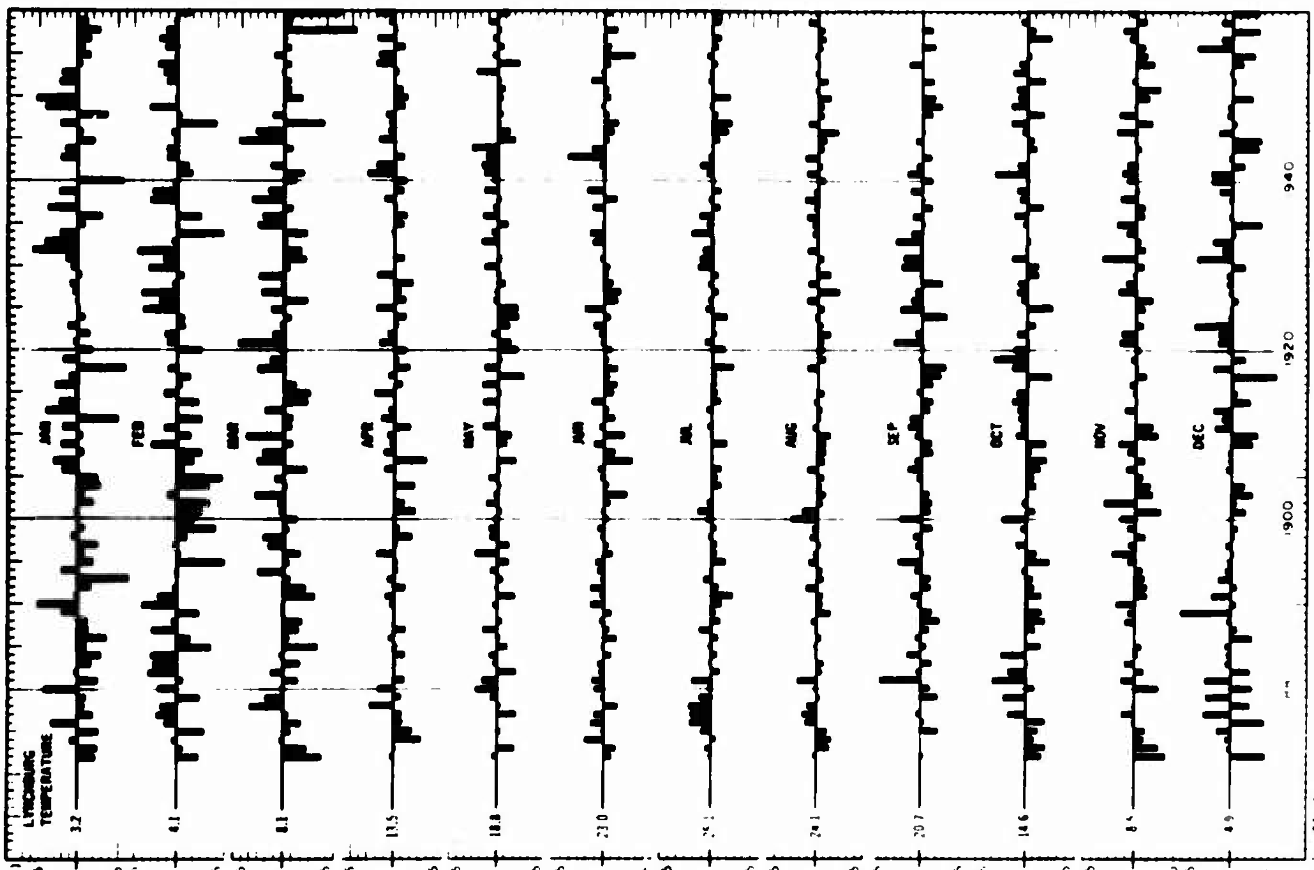

TEMPERATURE
MAR
FEB
JAN
APR
MAY
JUN
K(years) — 30

FIGURE 6B


LYNCHBURG TEMPERATURE
(°C)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
3.2
4.1
8.1
13.5
18.8
23.0
24.1
20.7
14.6
4.9
1900
1920
1940

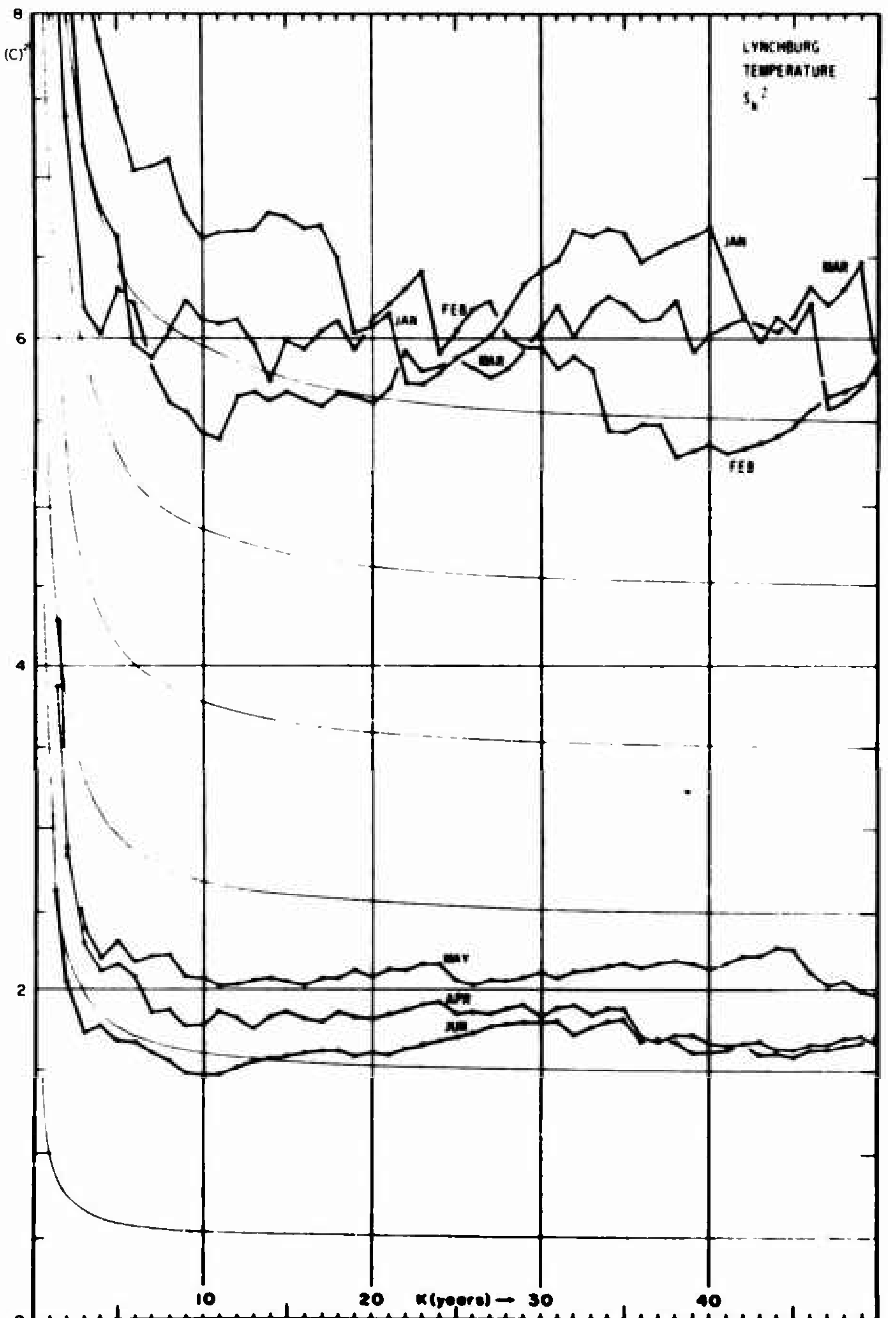


FIGURE 7B

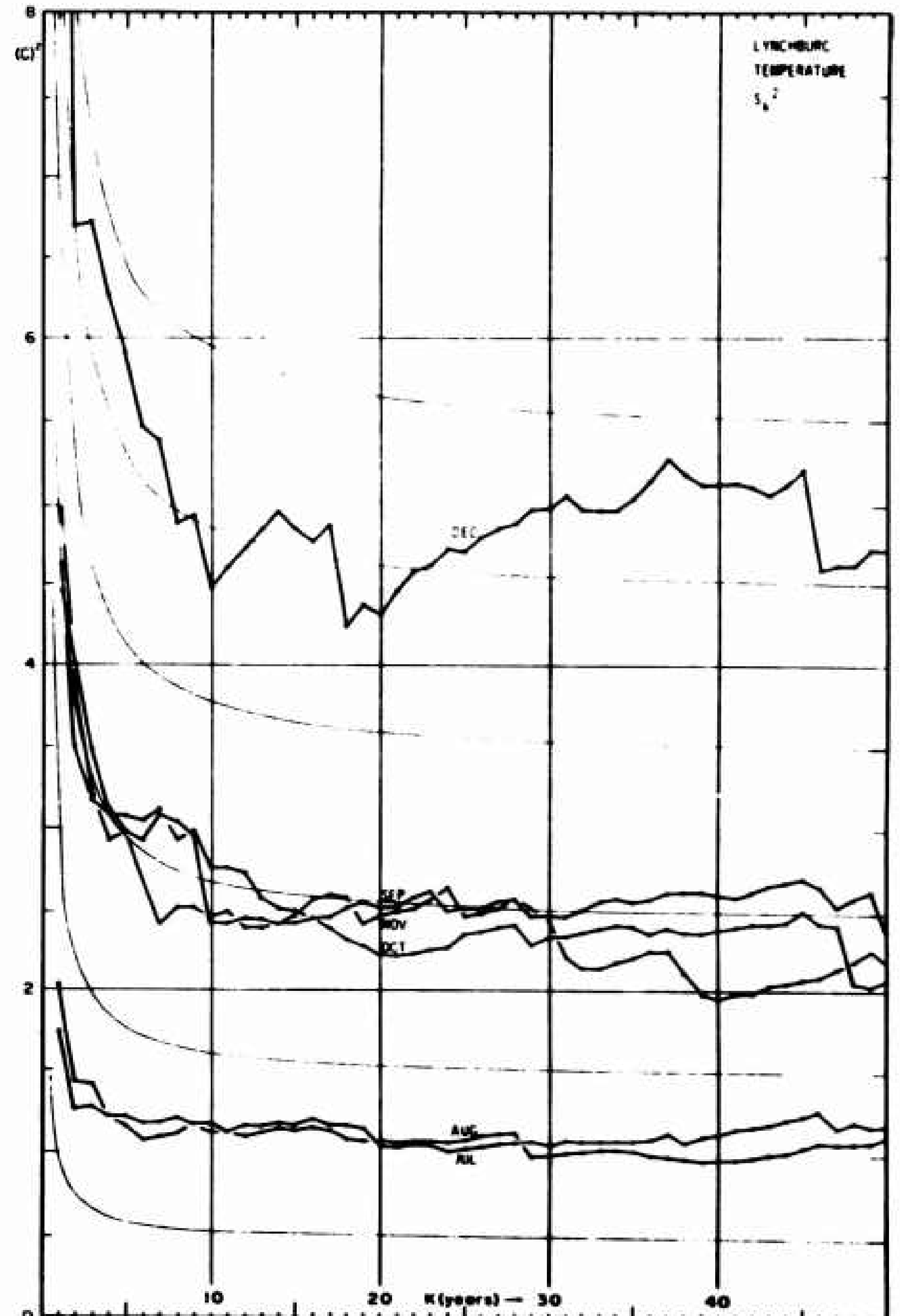


FIGURE 7C

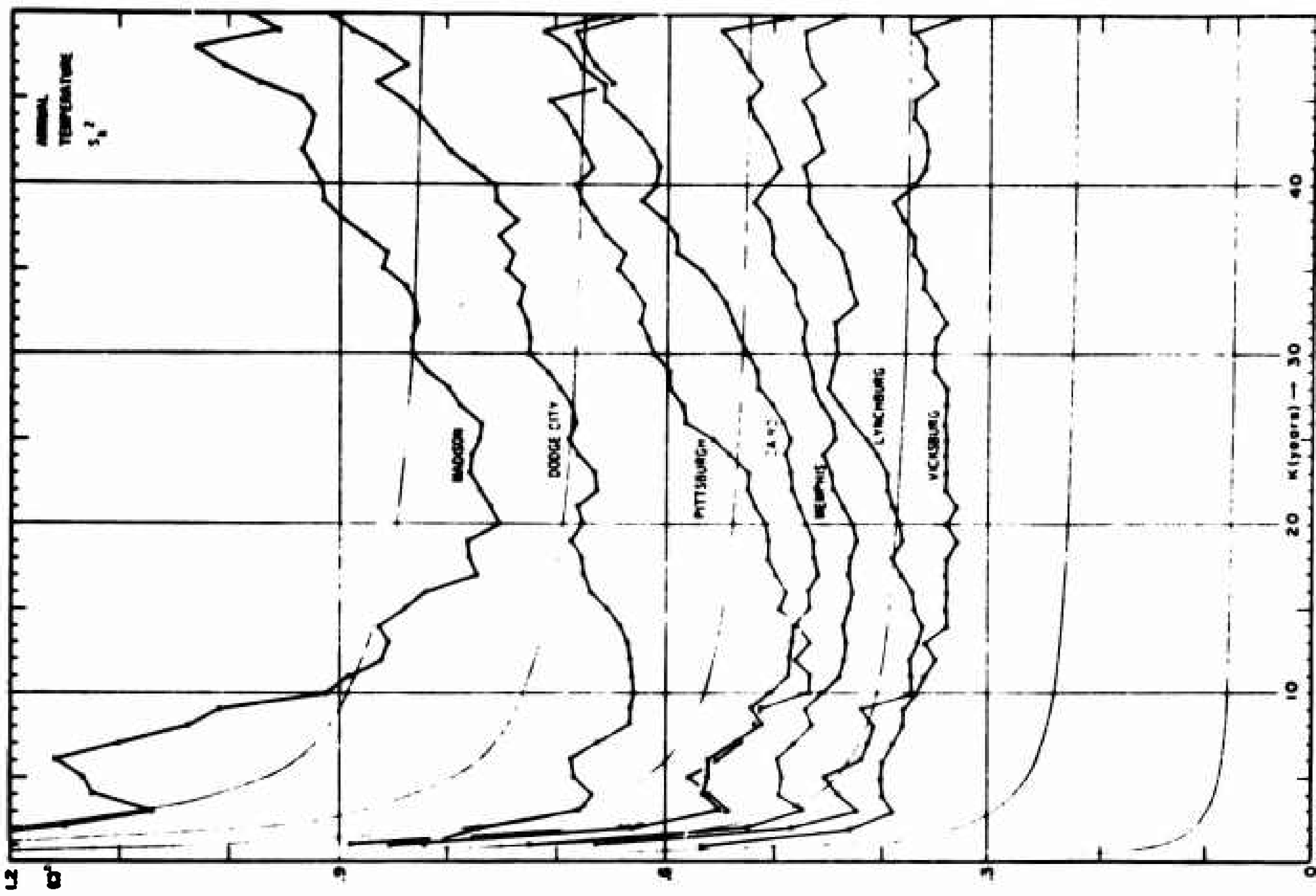


FIGURE 8B

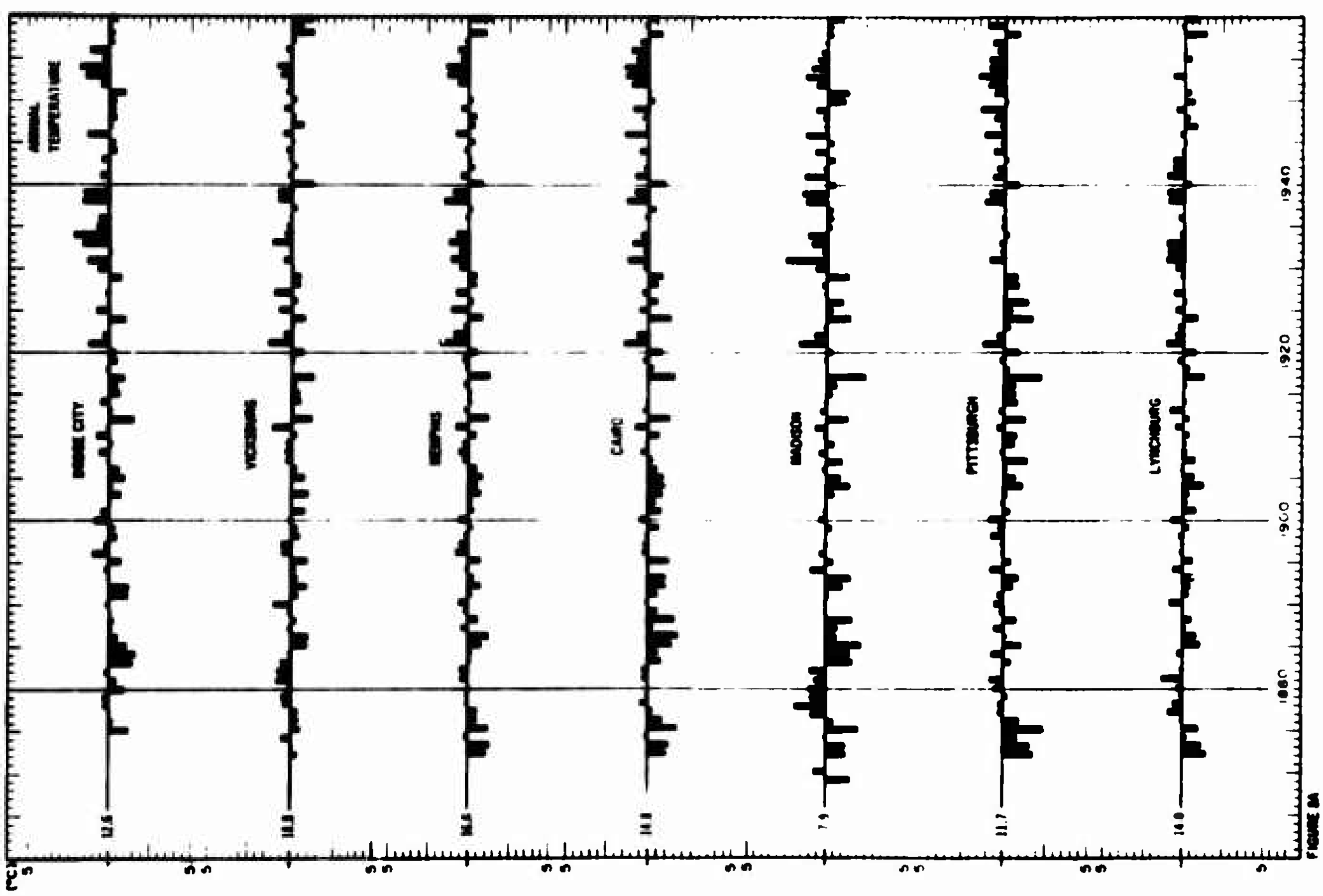


FIGURE 8A

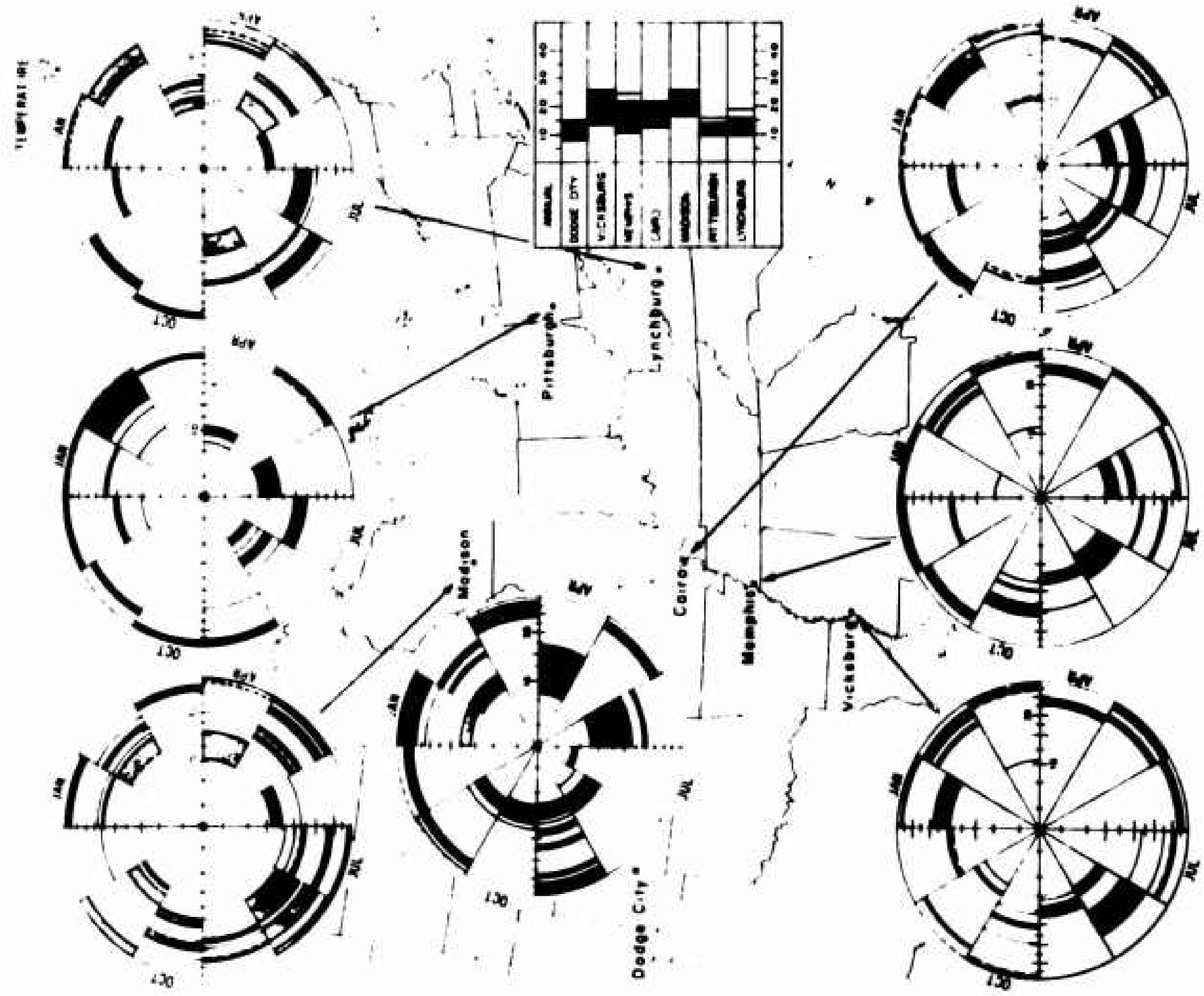

TEMPERATURE
JAN
APR
JUL
OCT
ANNUAL
DODGE CITY
VICKSBURG
MEMPHIS
MADISON
PITTSBURGH
LYNCHBURG
10 20 30 40
Pittsburgh
Lynchburg
Madison
Dodge City
Cairo
Memphis
Vicksburg

FIGURE 9

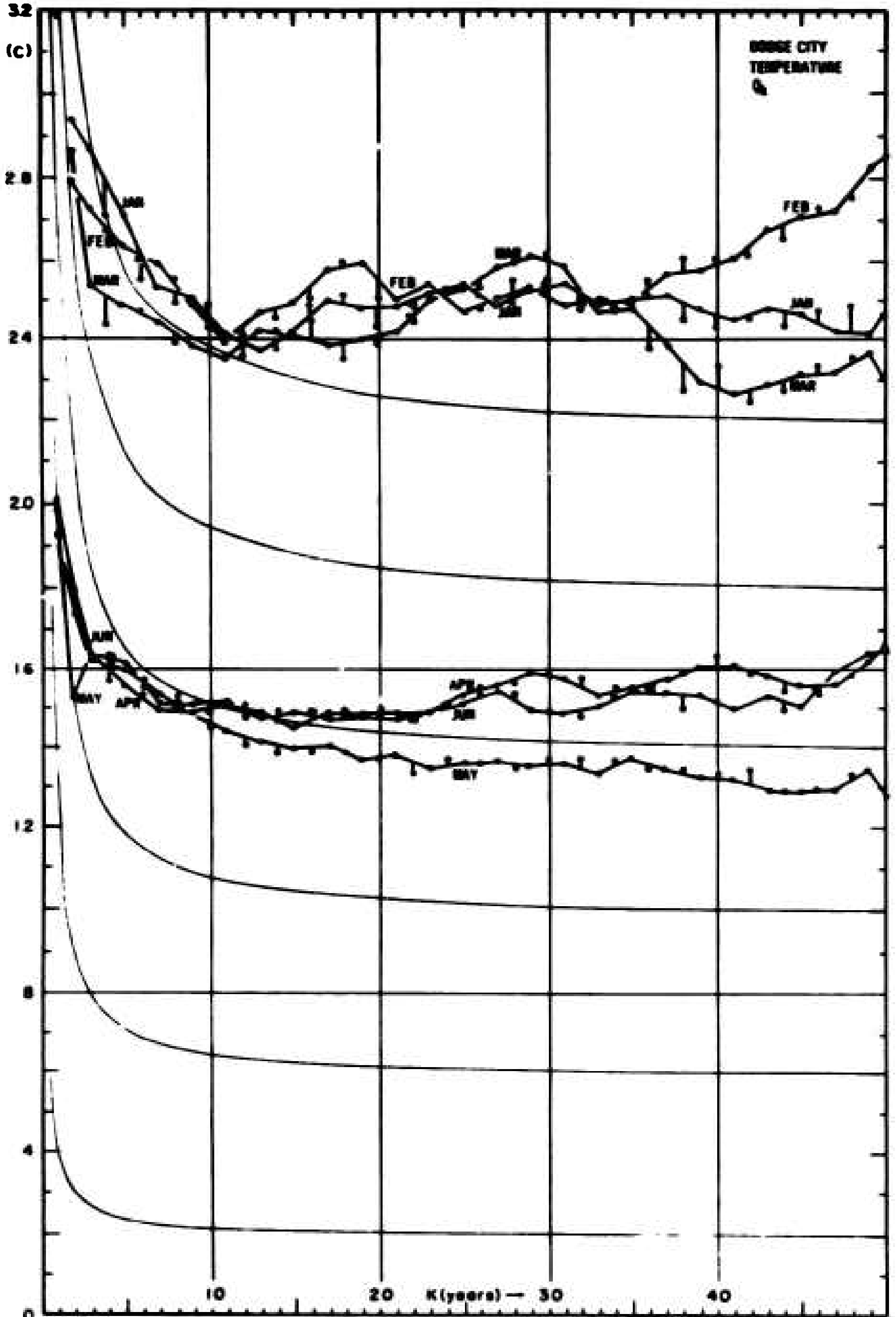


FIGURE 10A

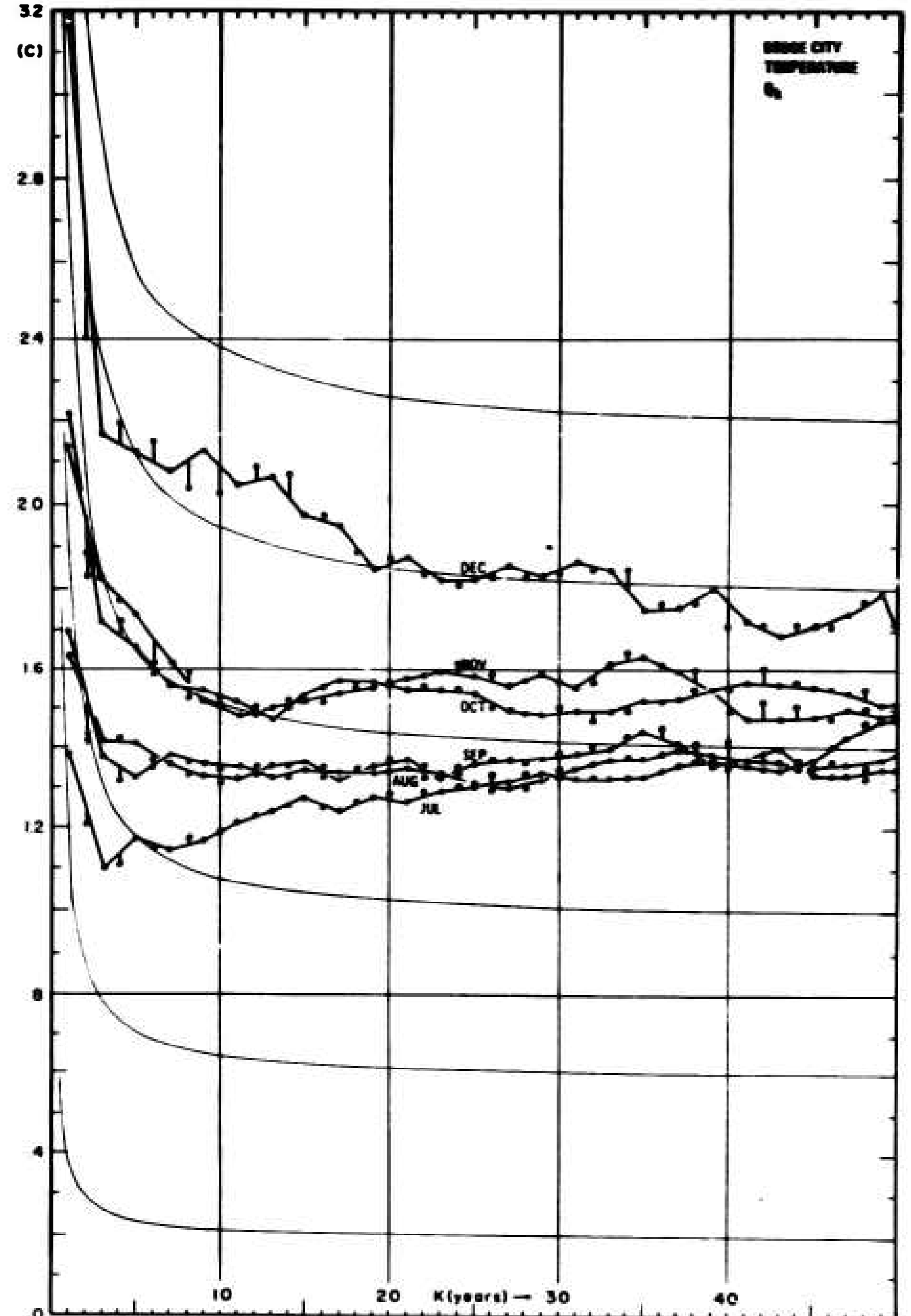


FIGURE 10B

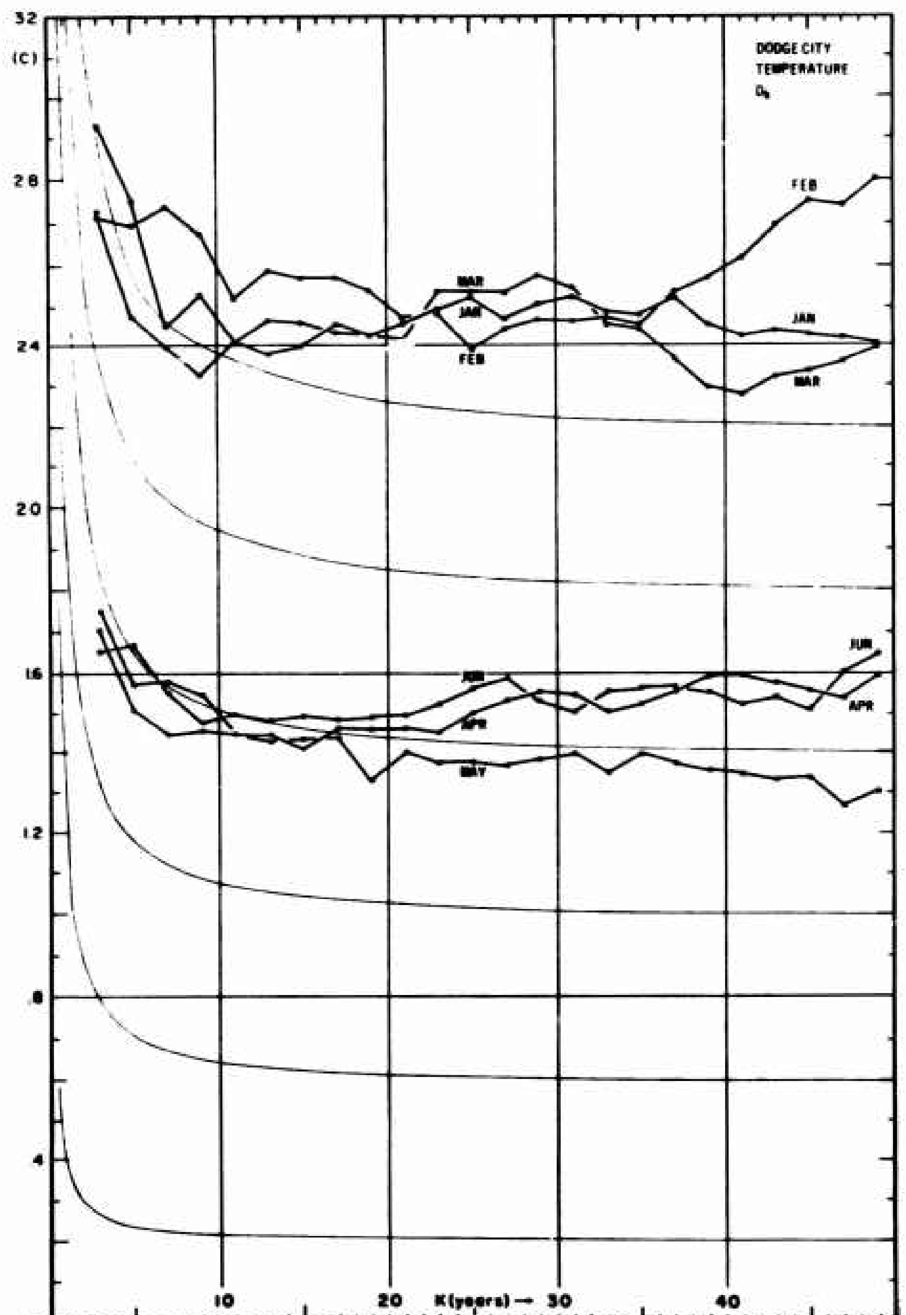


FIGURE 11C

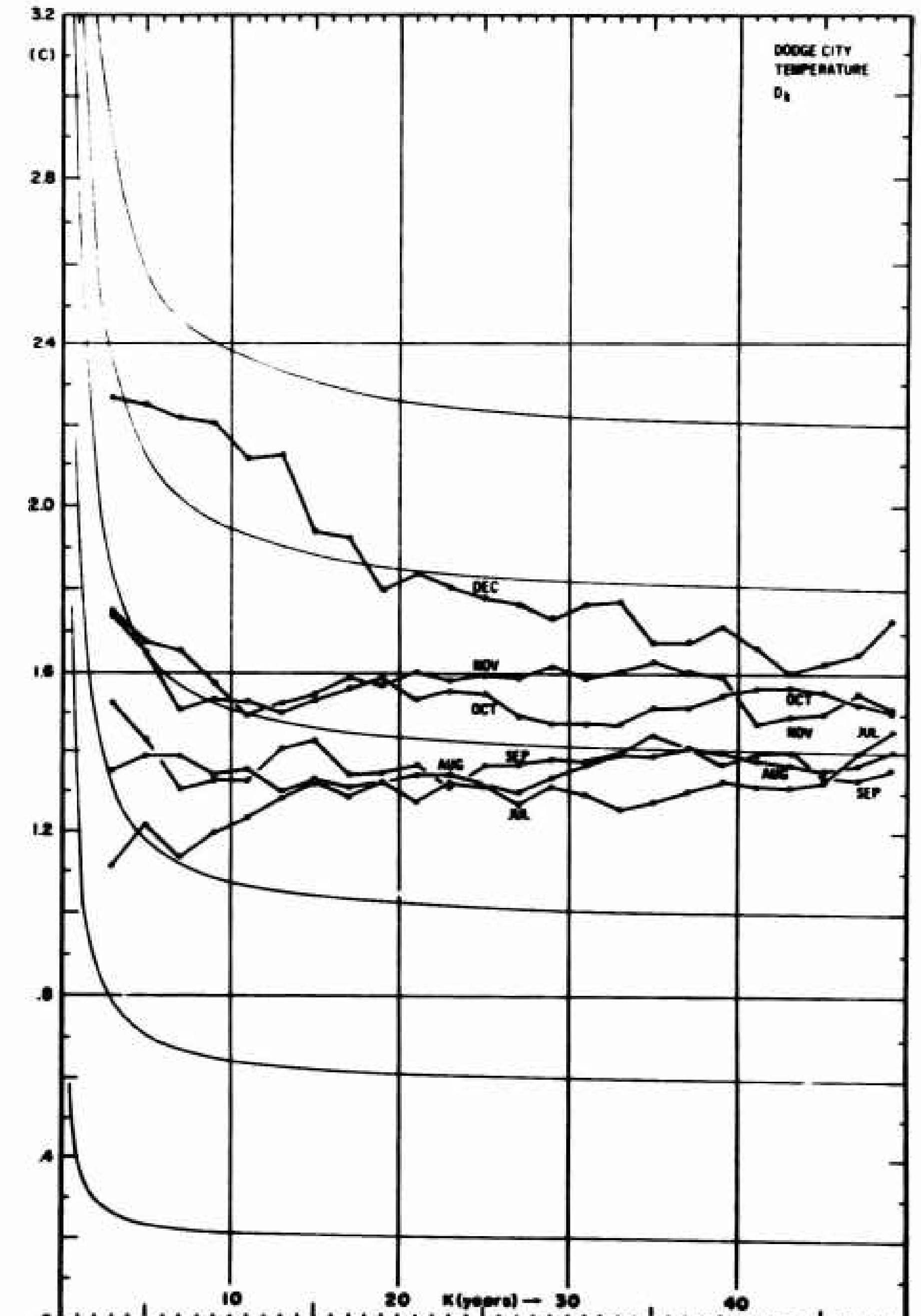


FIGURE 11D

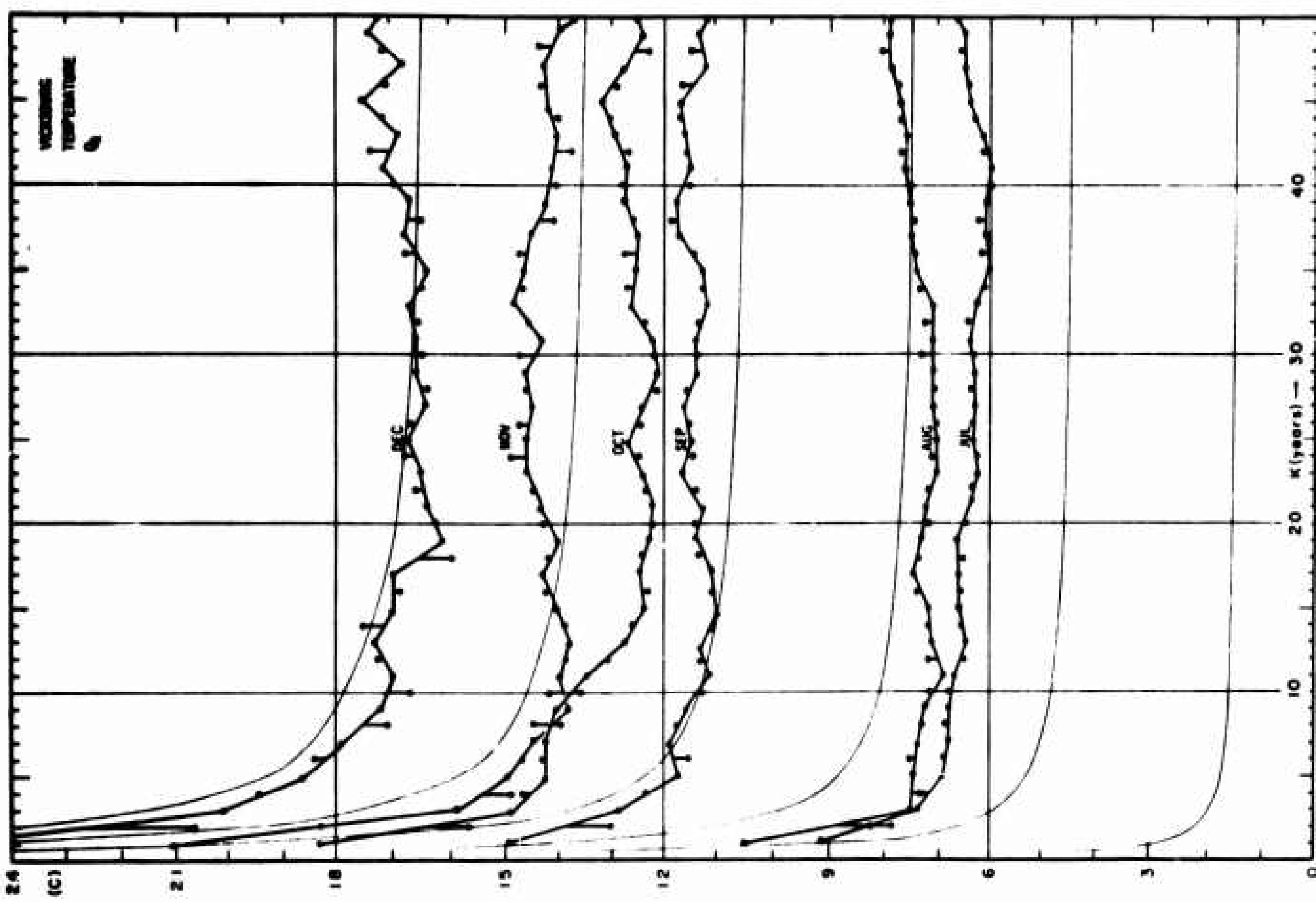


FIGURE 11B

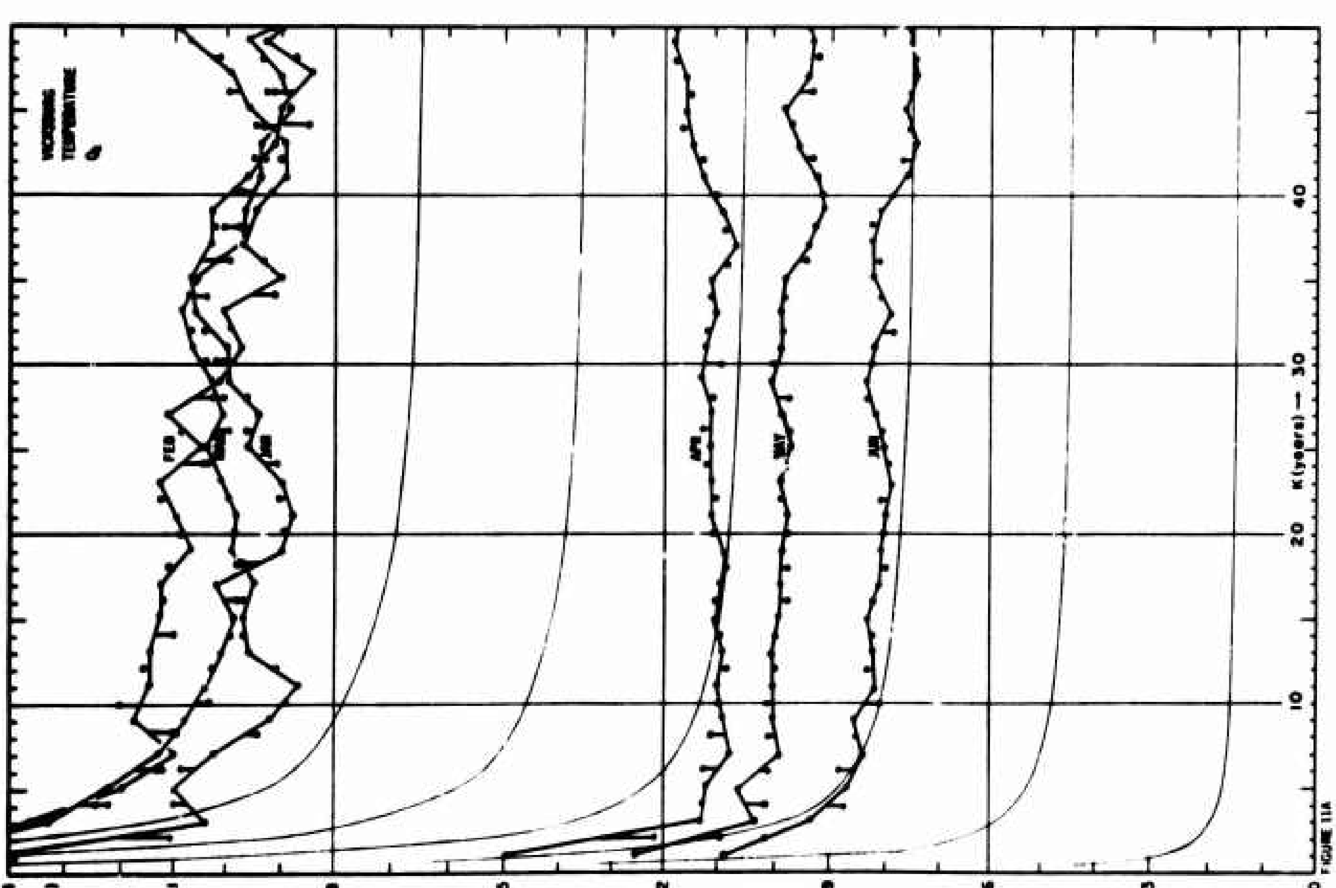


FIGURE 11A

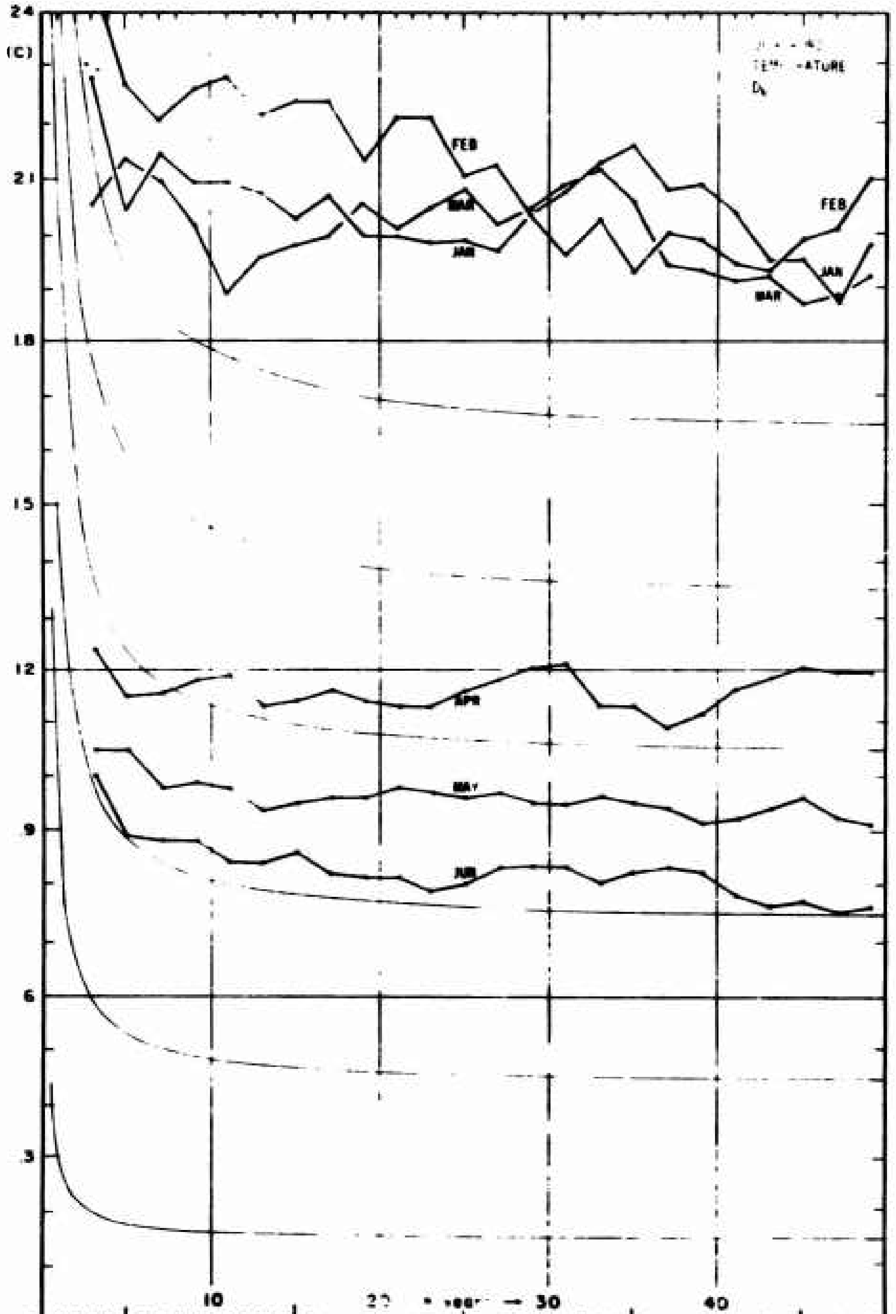
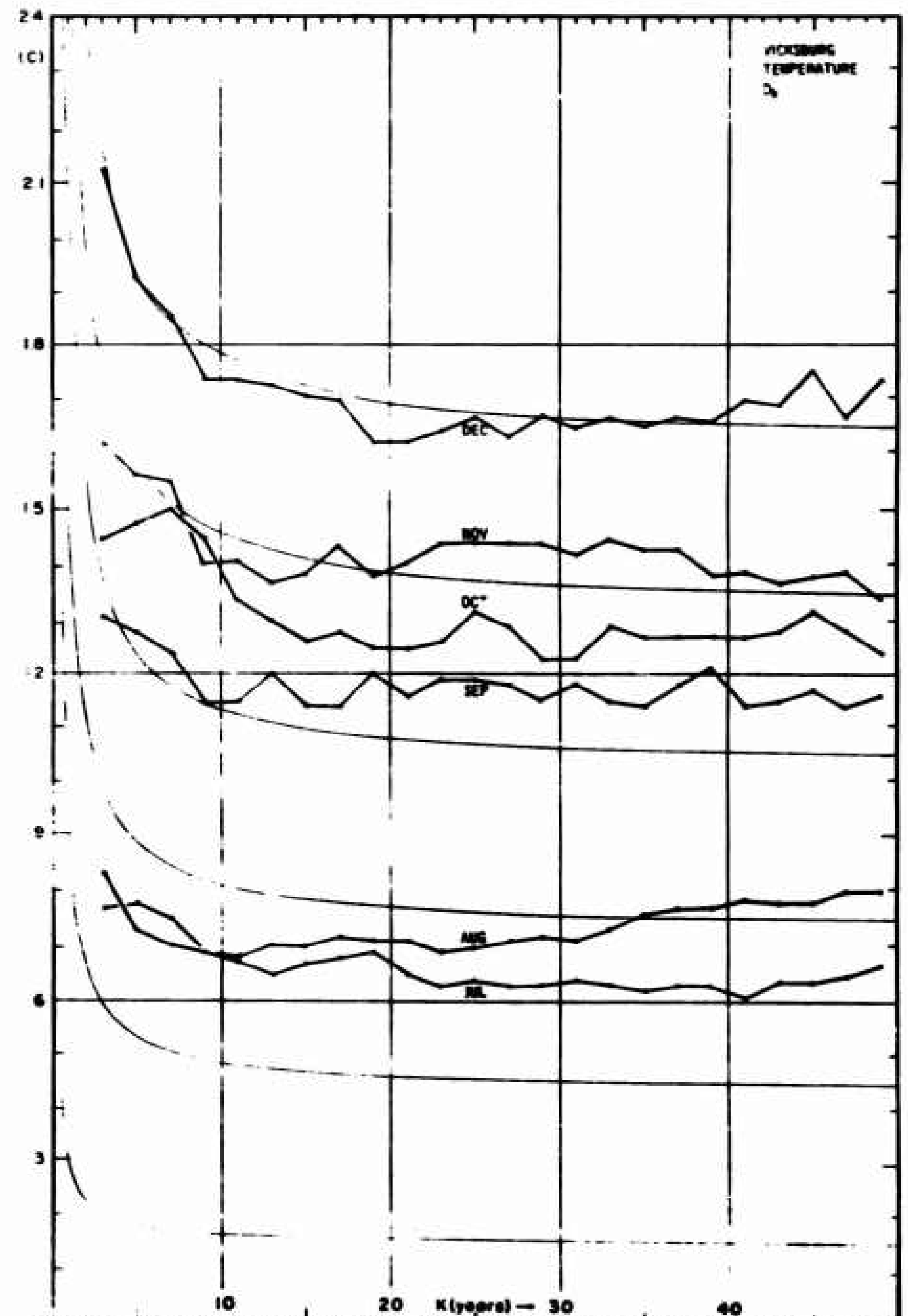

24
(C)
21
18
15
12
9
6
3
0
FEB
MAR
JAN
APR
MAY
JUN
10
30
40

FIGURE IIC


VICKSBURG
TEMPERATURE
24
(C)
21
18
15
9
6
3
DEC
NOV
SEP
AUG
JUL
10
20
K(years) — 30
40

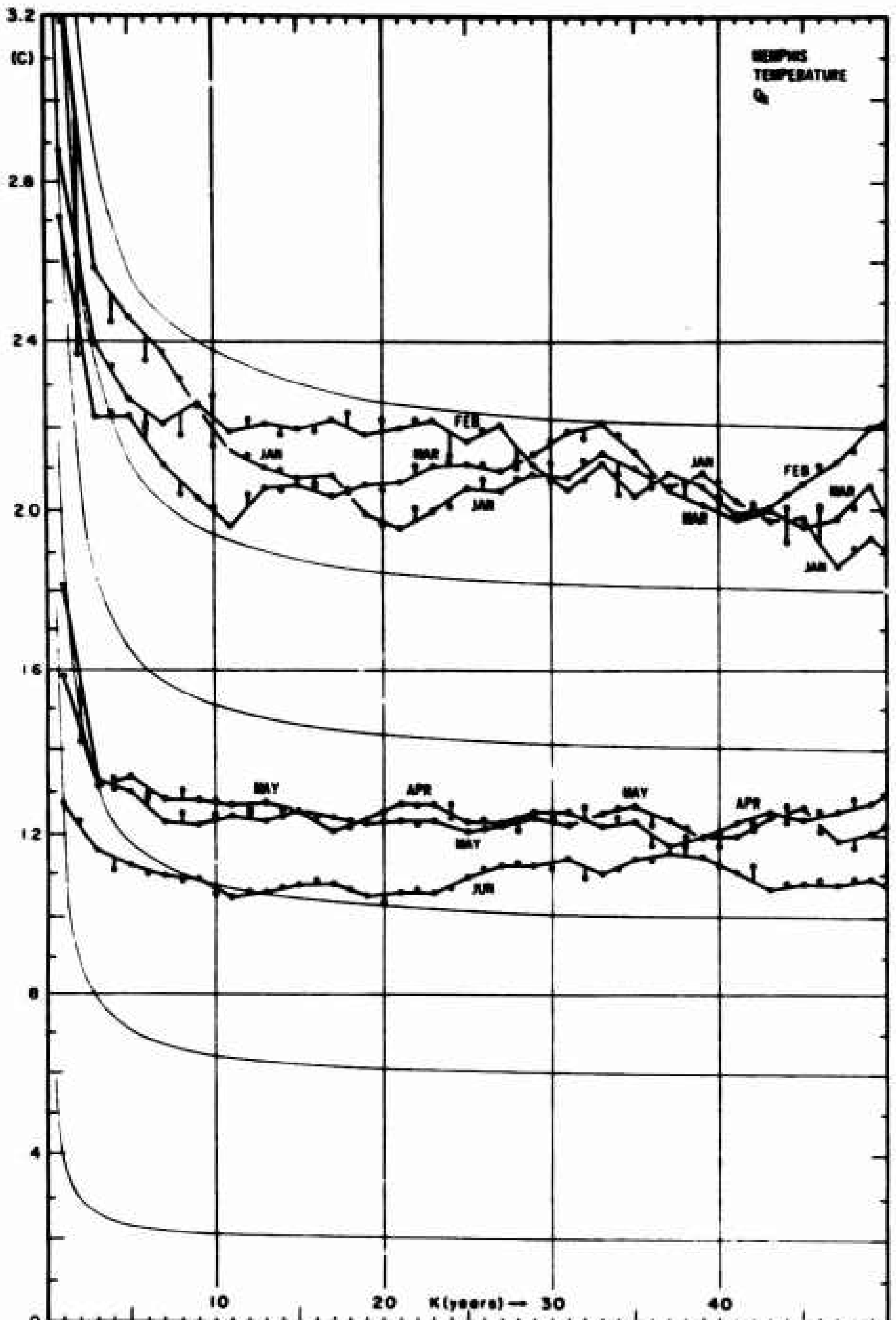


FIGURE 12A

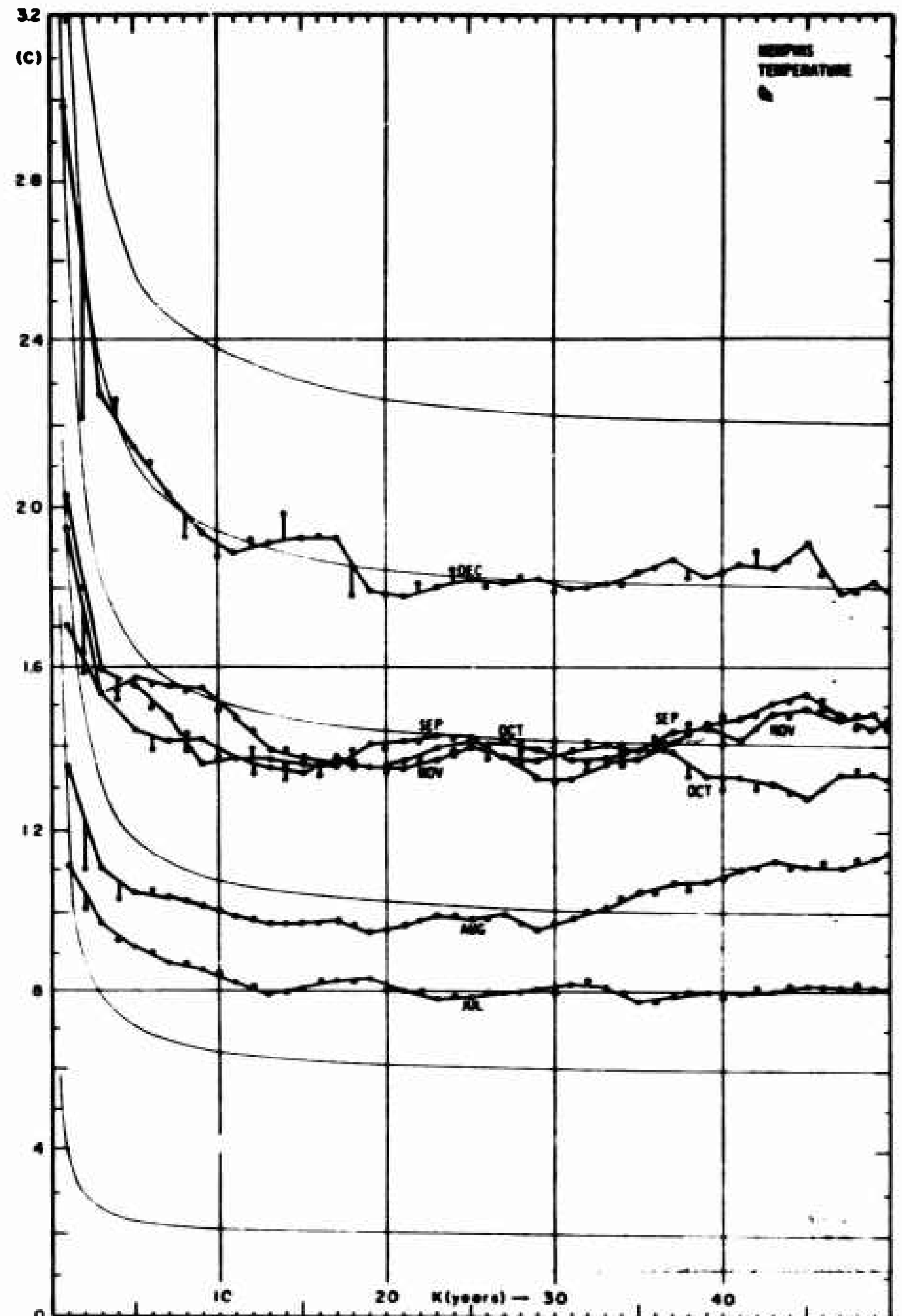


FIGURE 12B

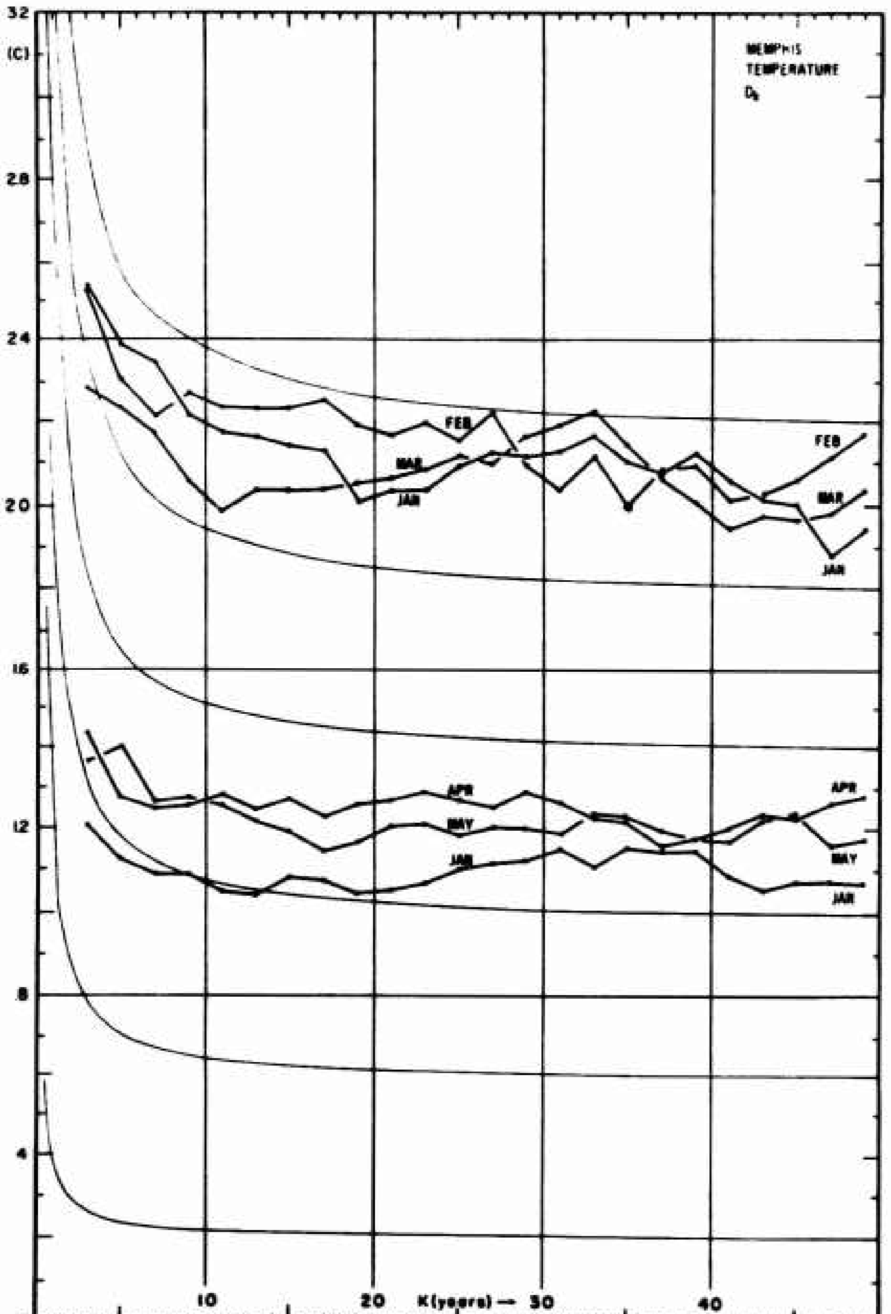


FIGURE 12C

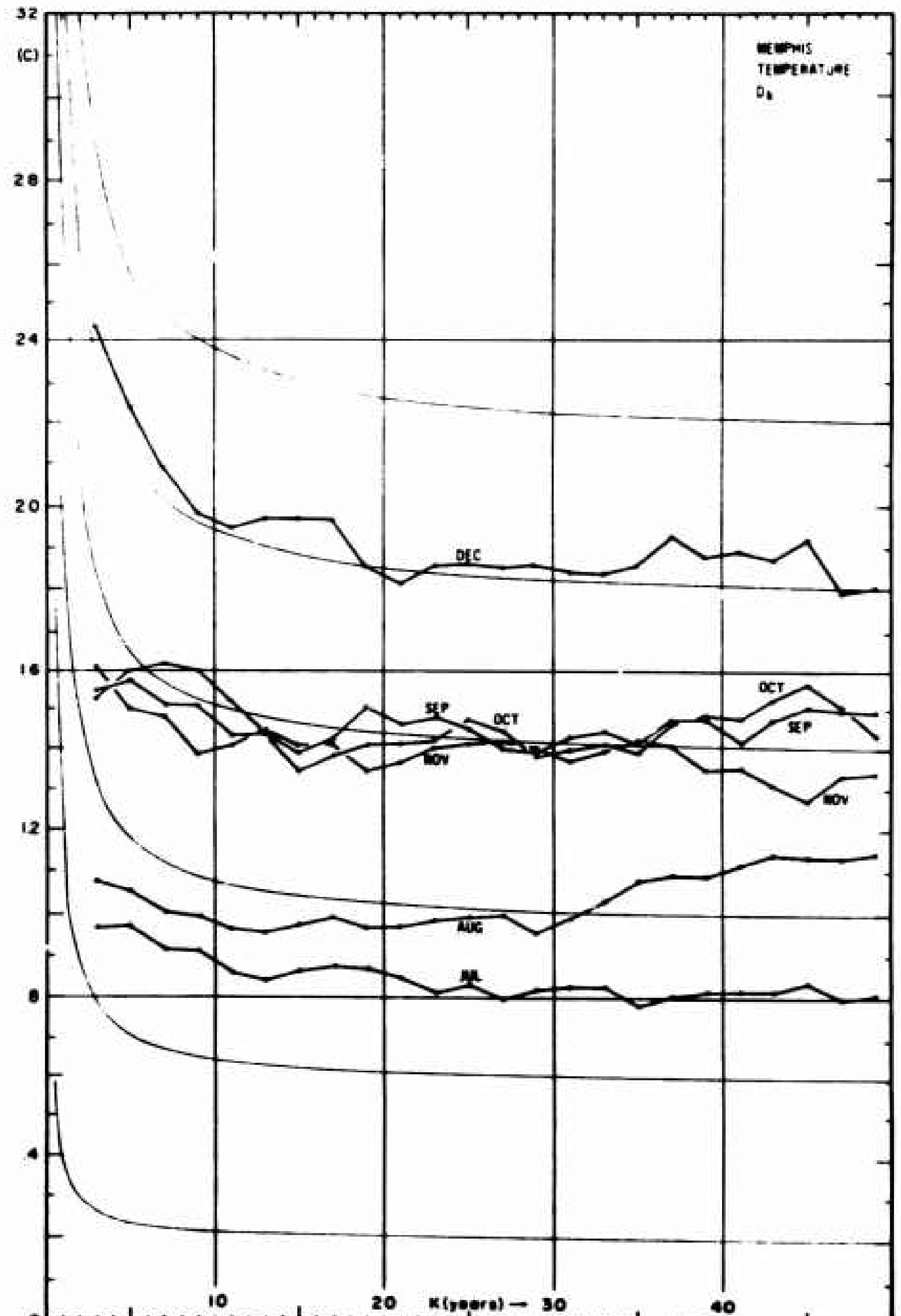


FIGURE 12D

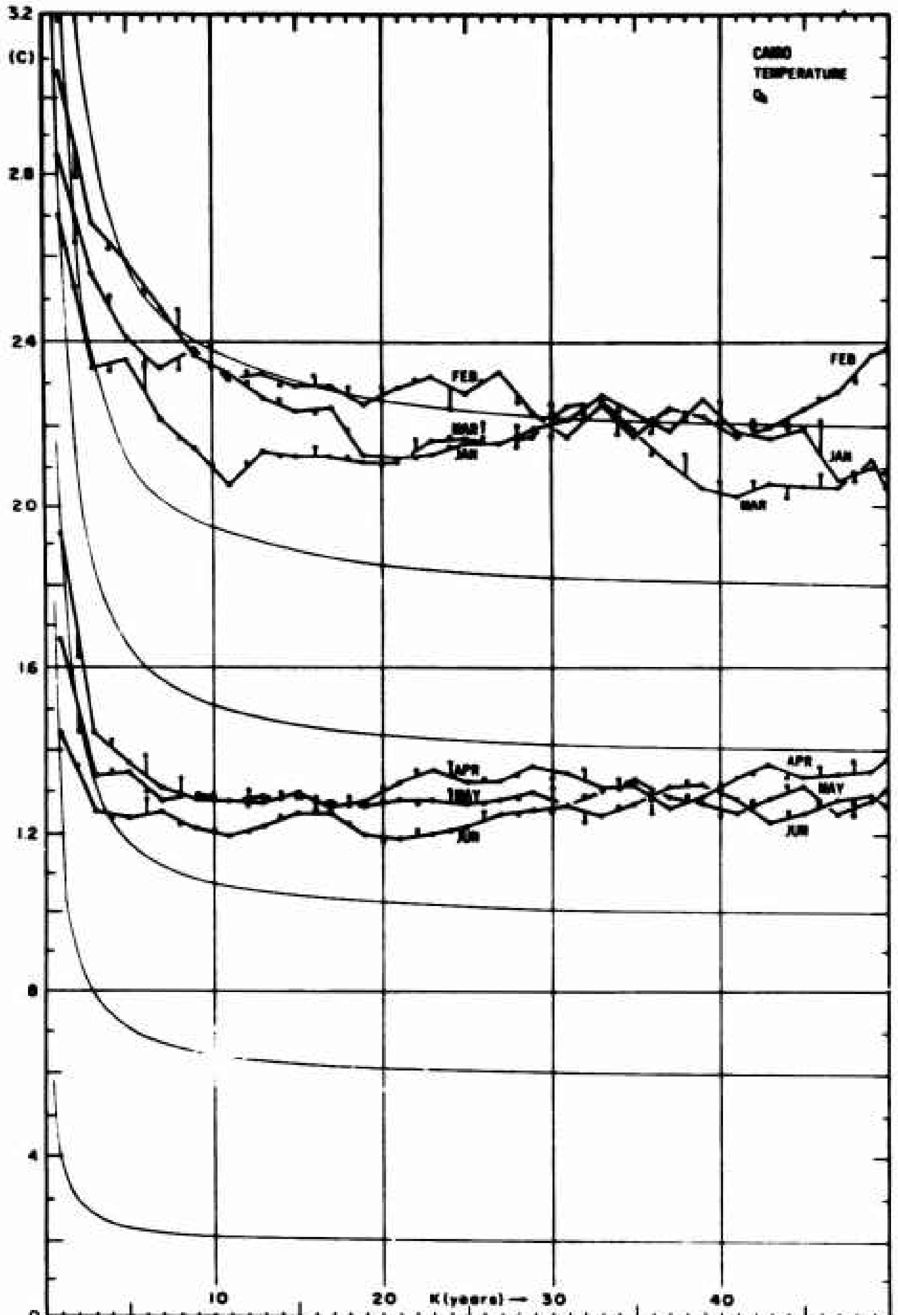


FIGURE 13A

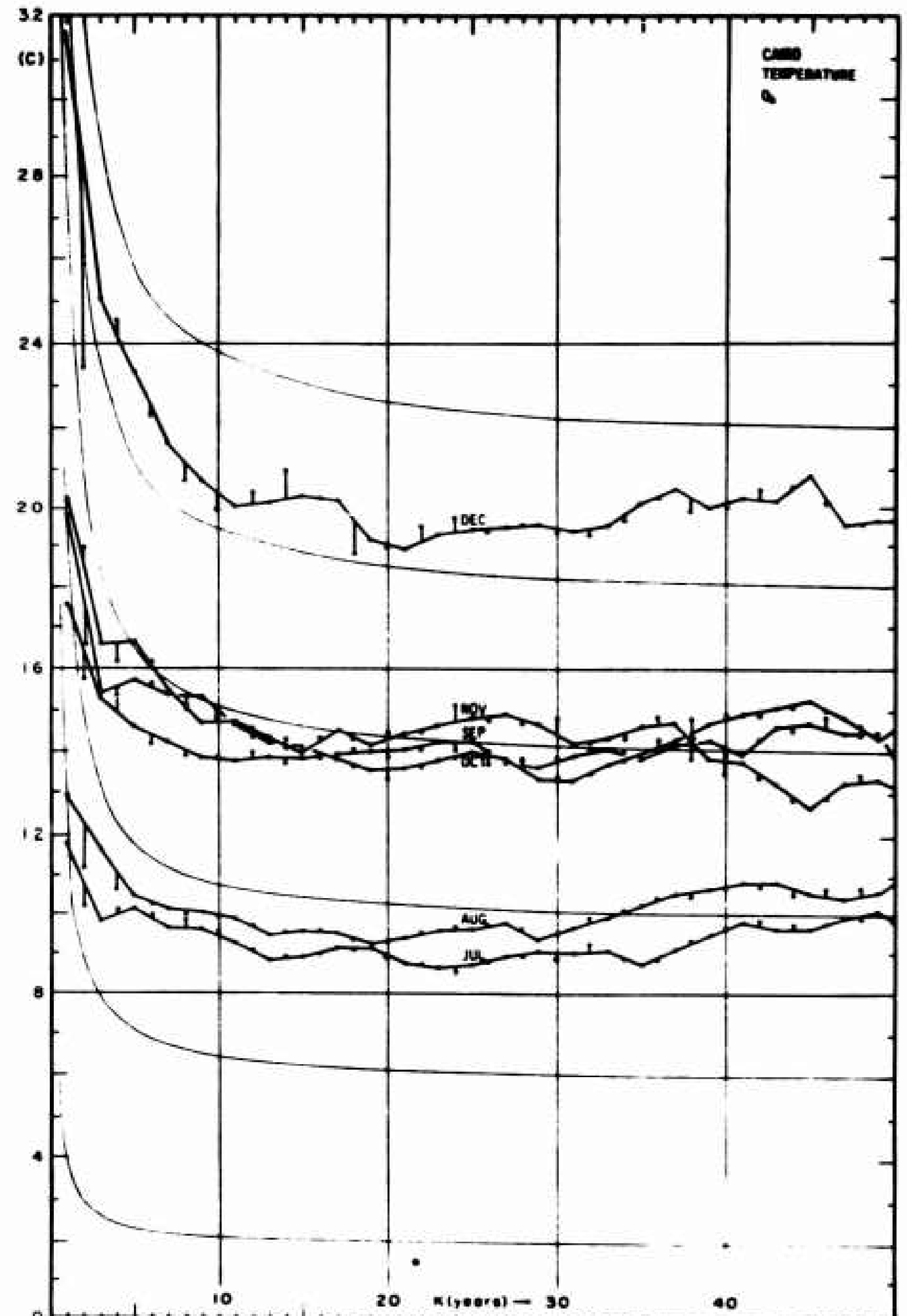


FIGURE 13B

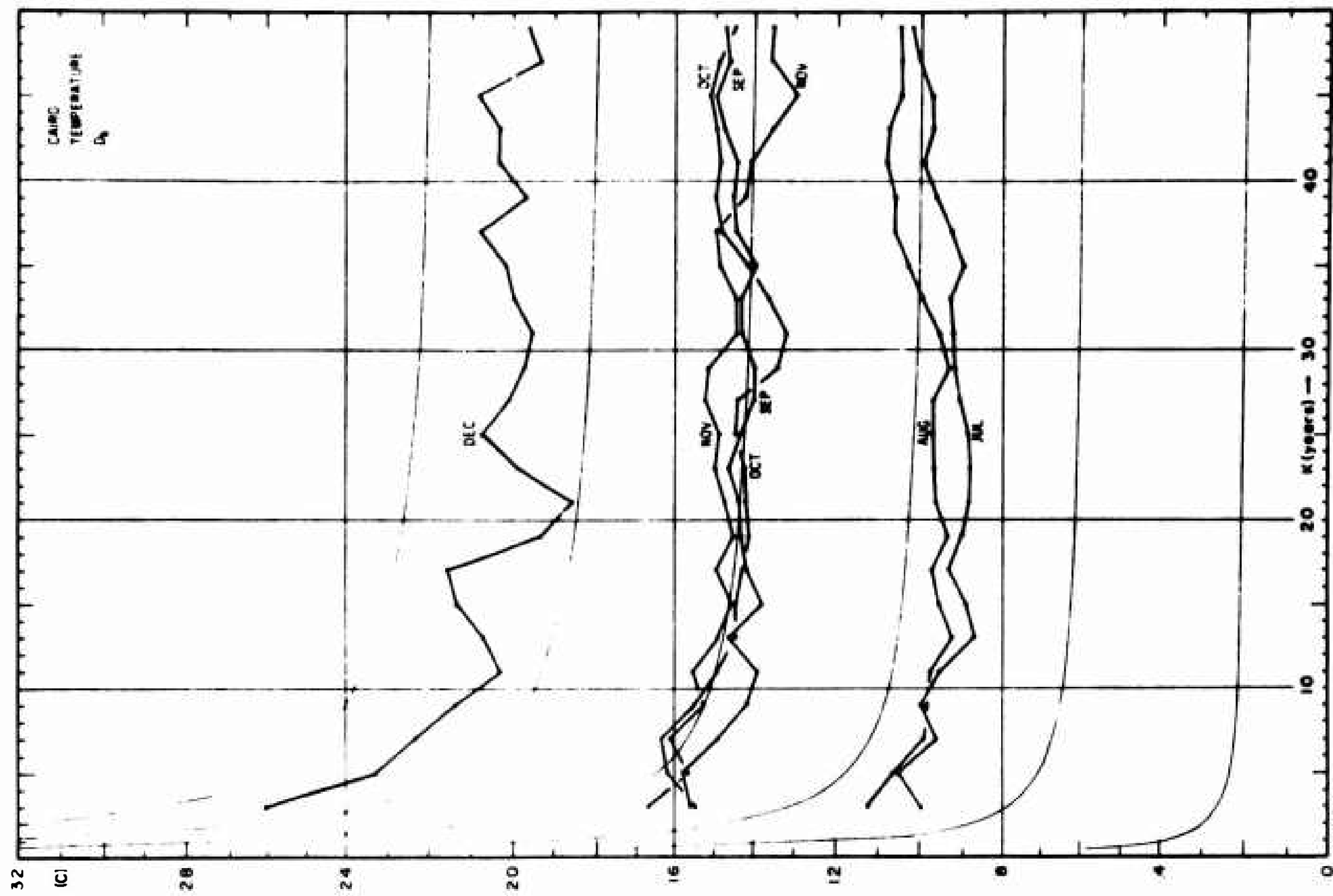


FIGURE 13D

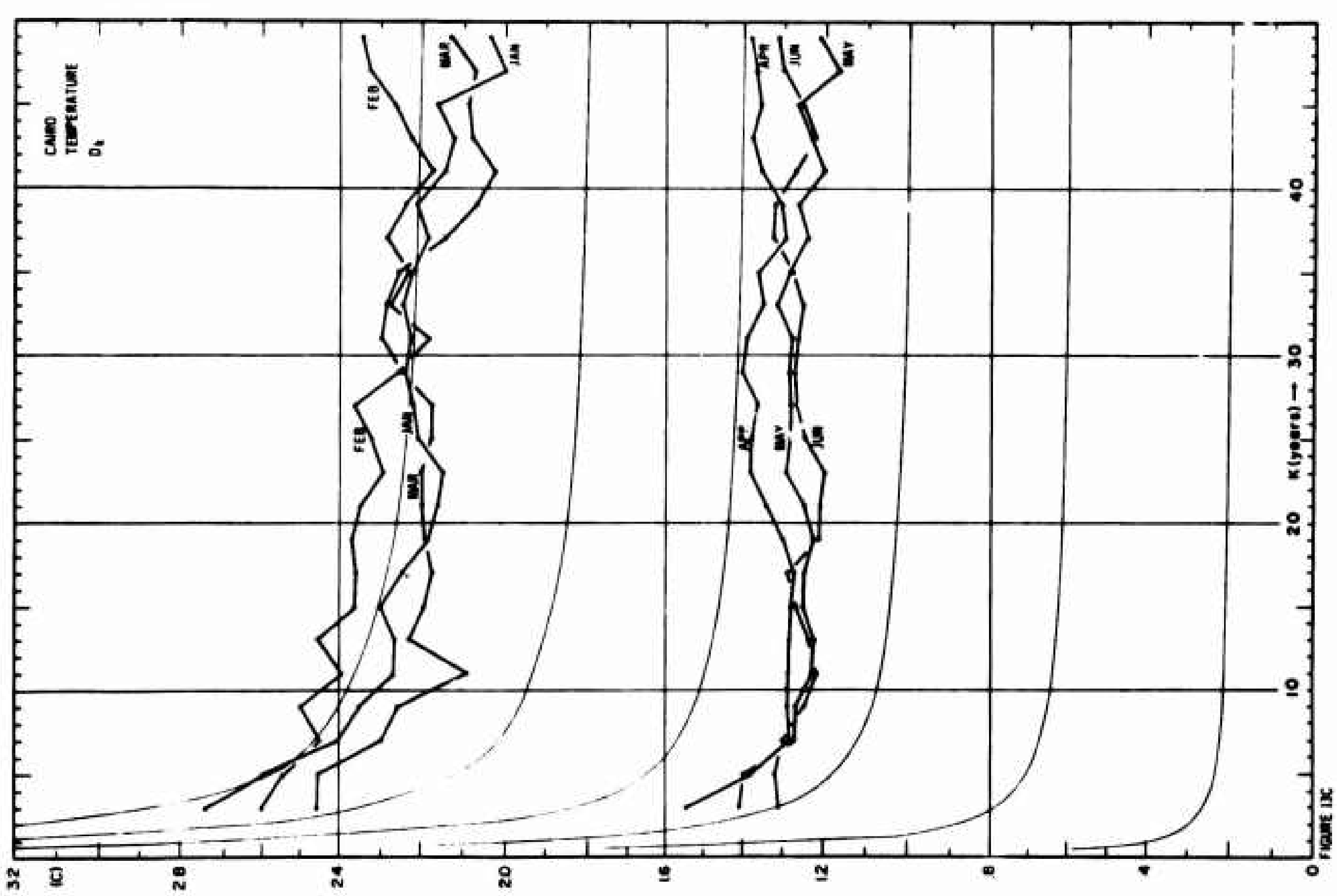


FIGURE 13C

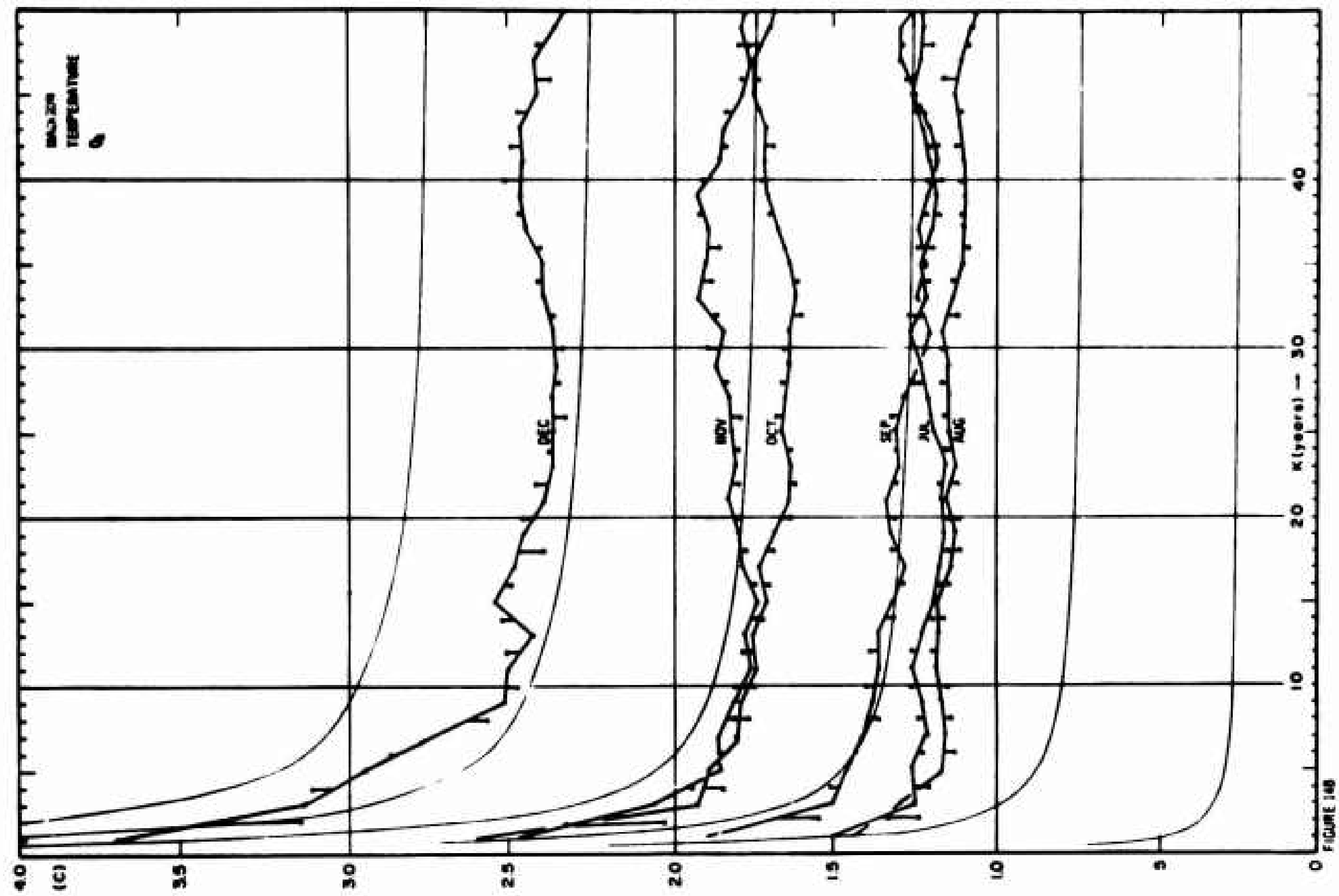


FIGURE 14B

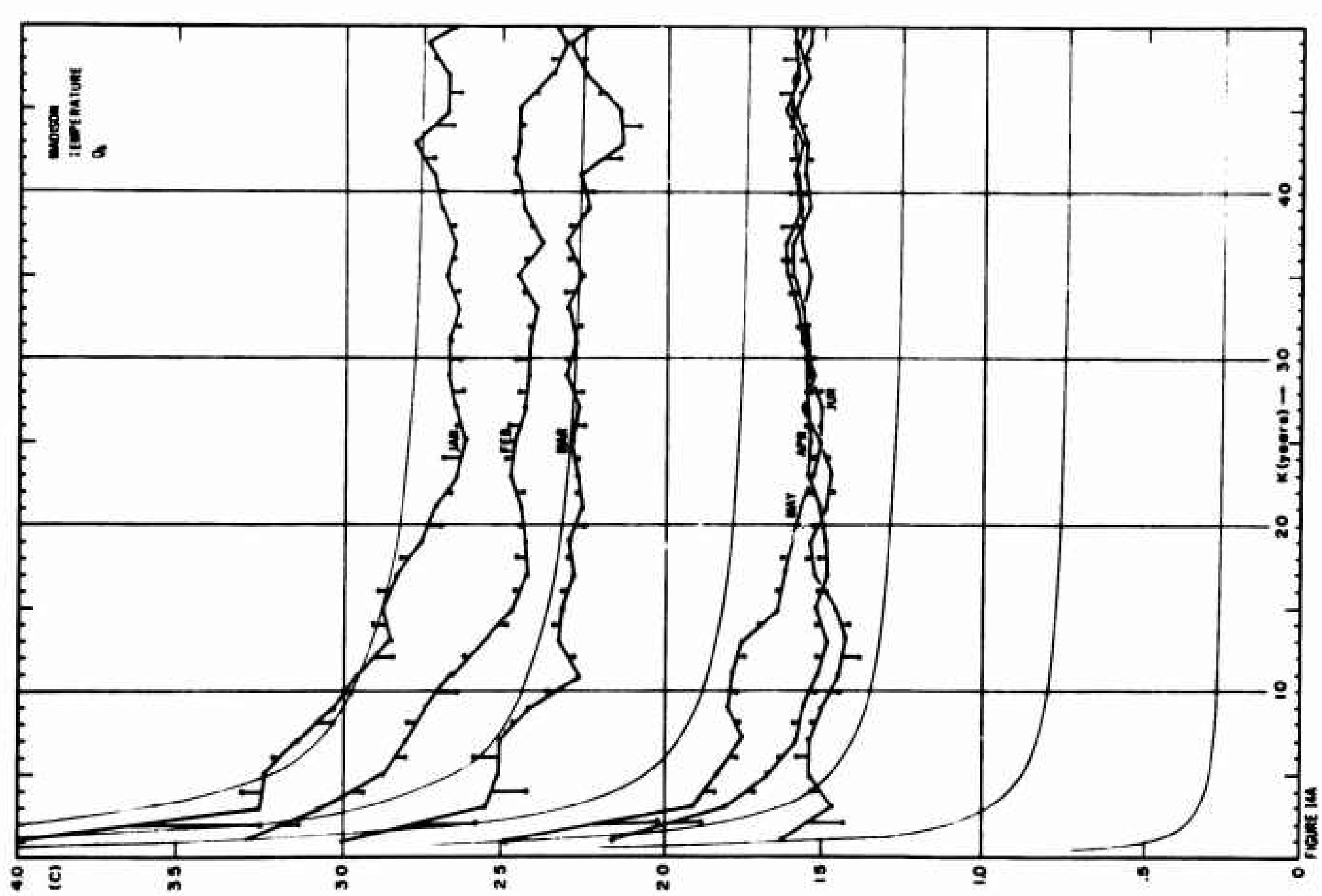


FIGURE 14A

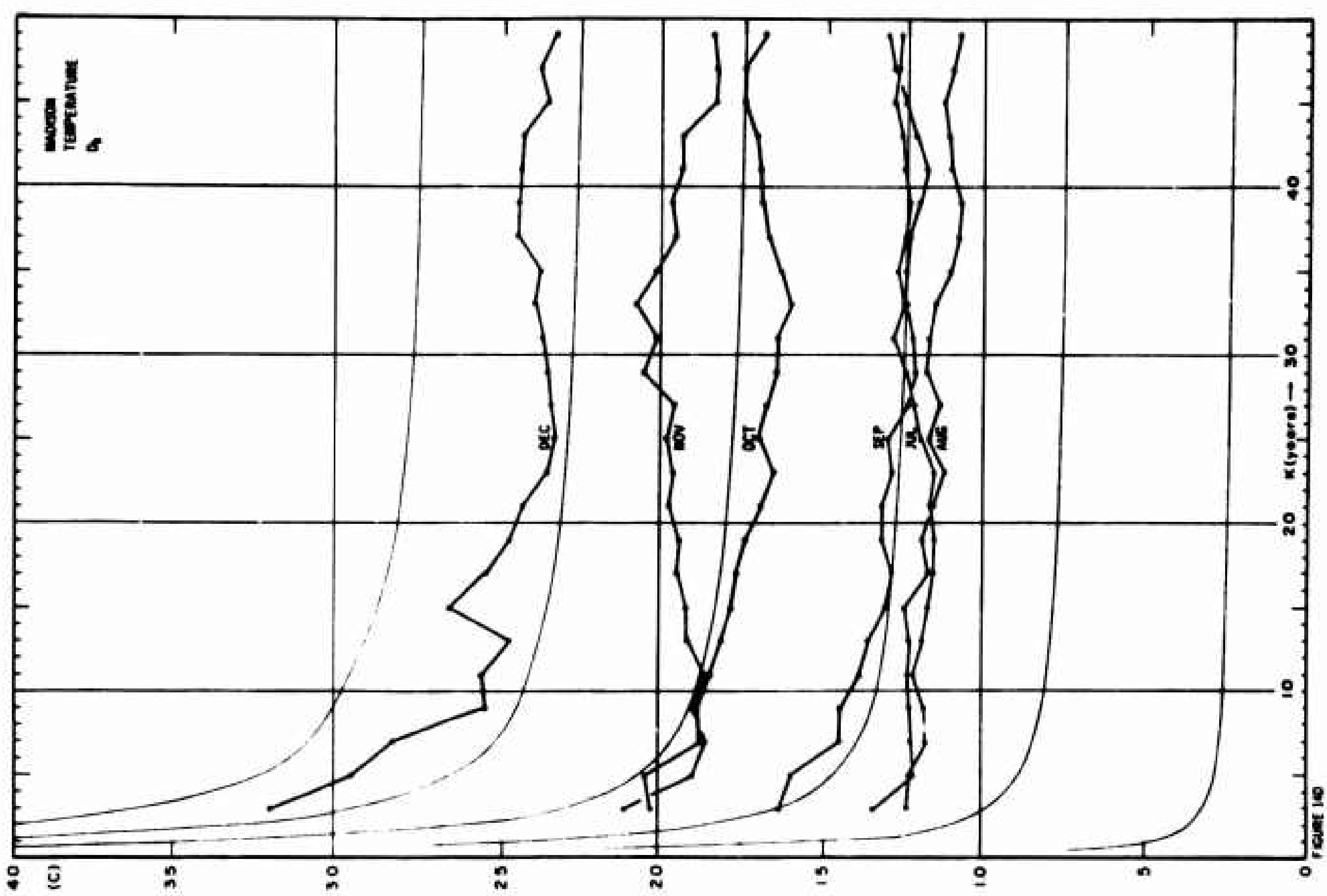


FIGURE 1D

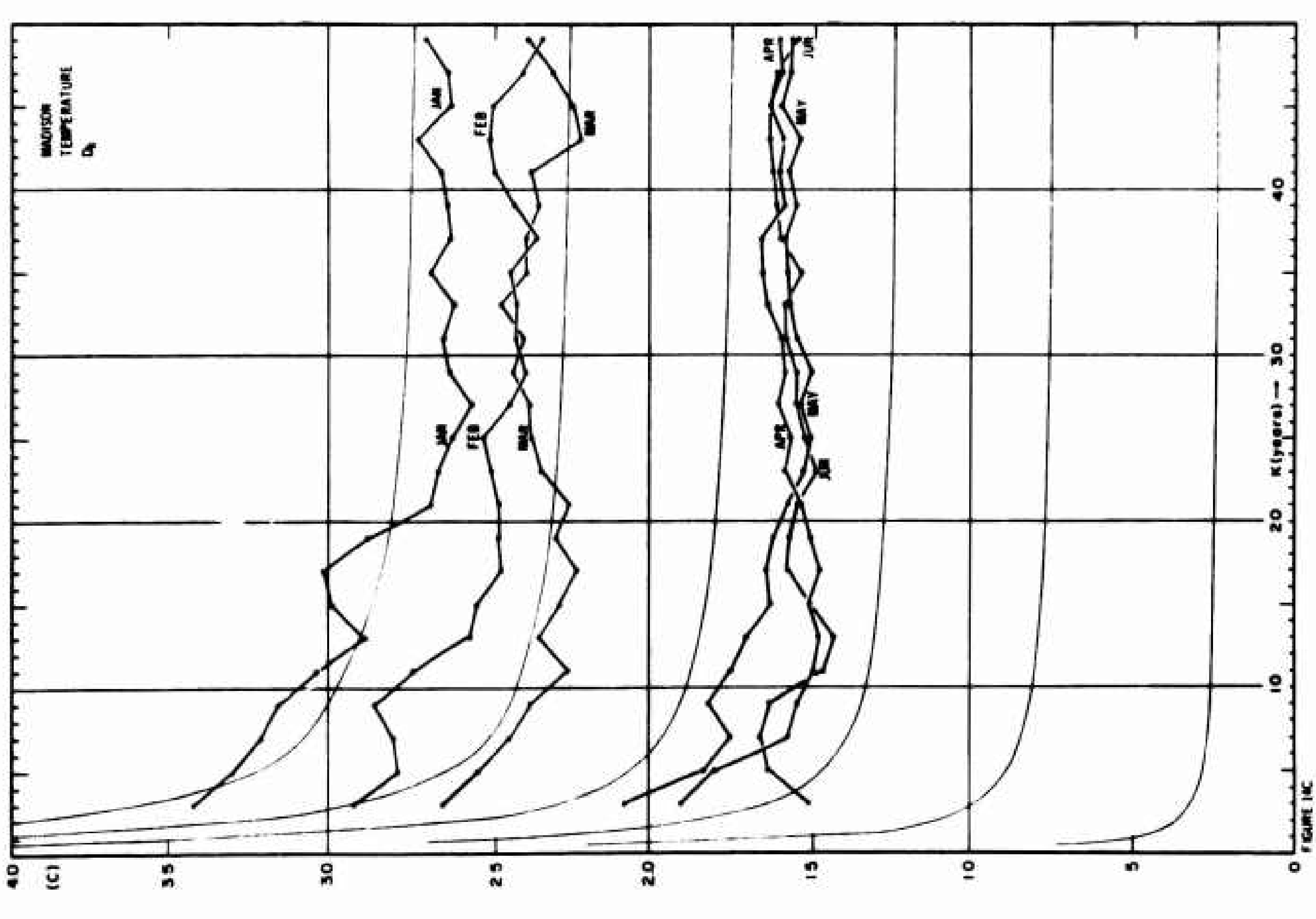


FIGURE 1C

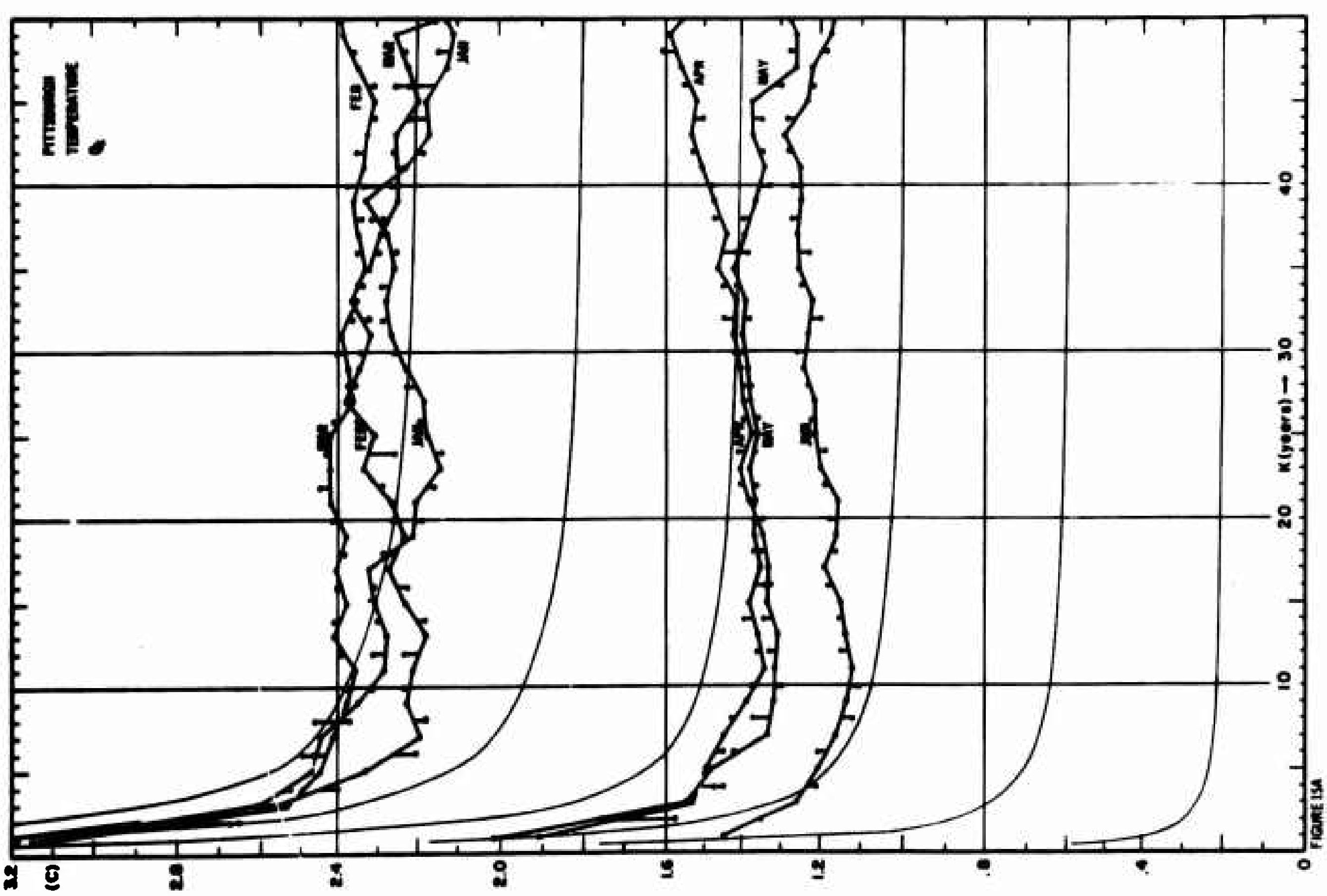


FIGURE 15A

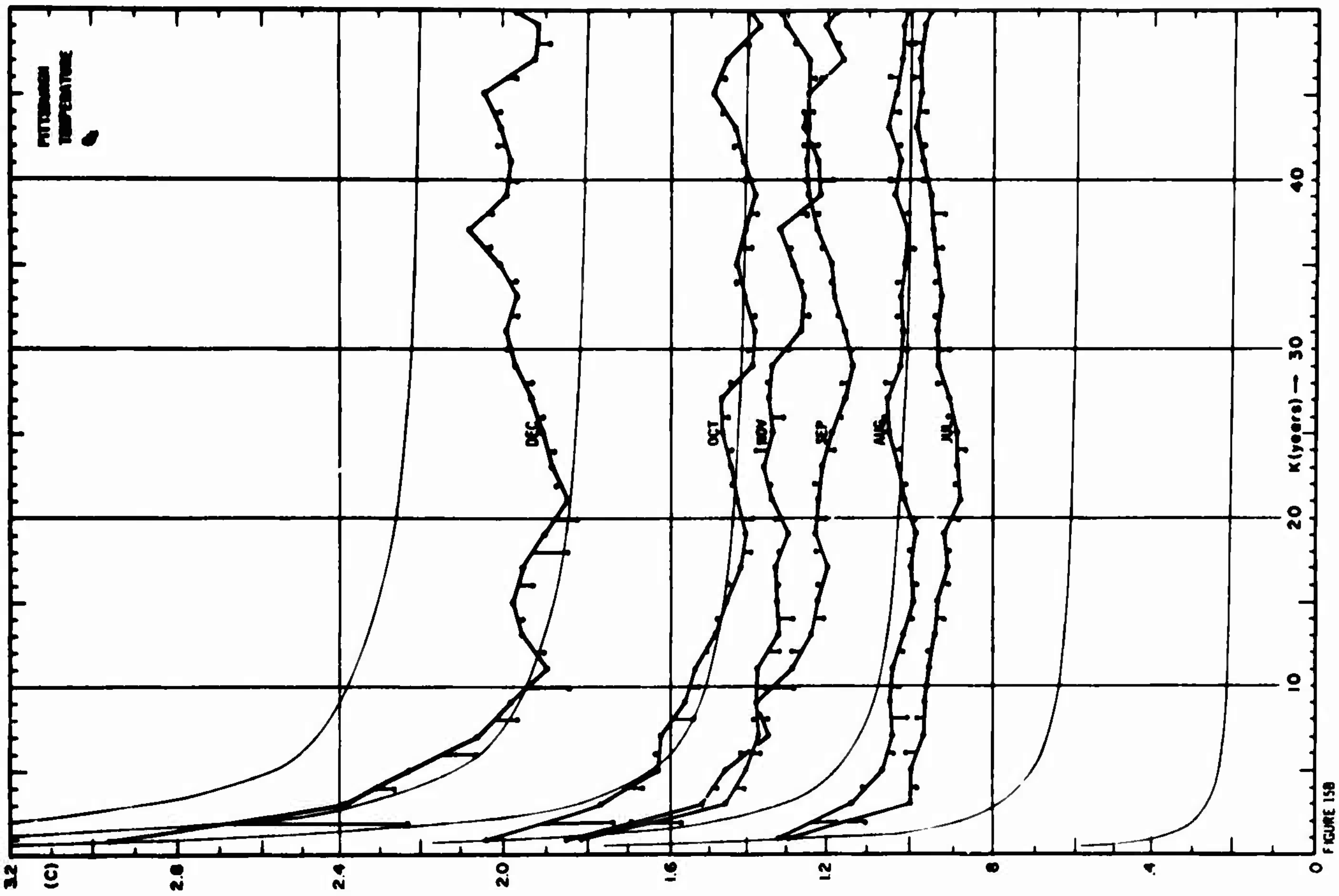


FIGURE 15B

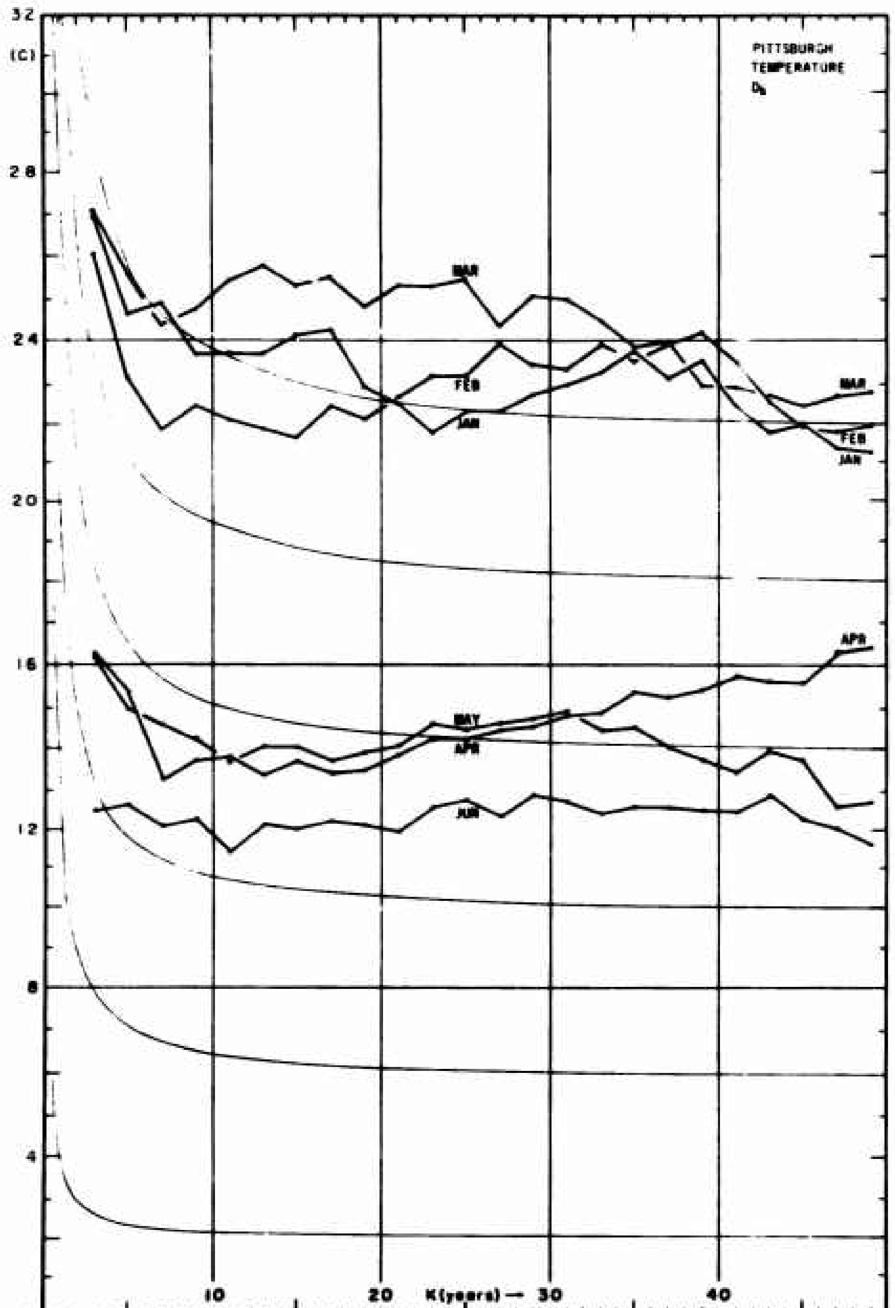


FIGURE 15C

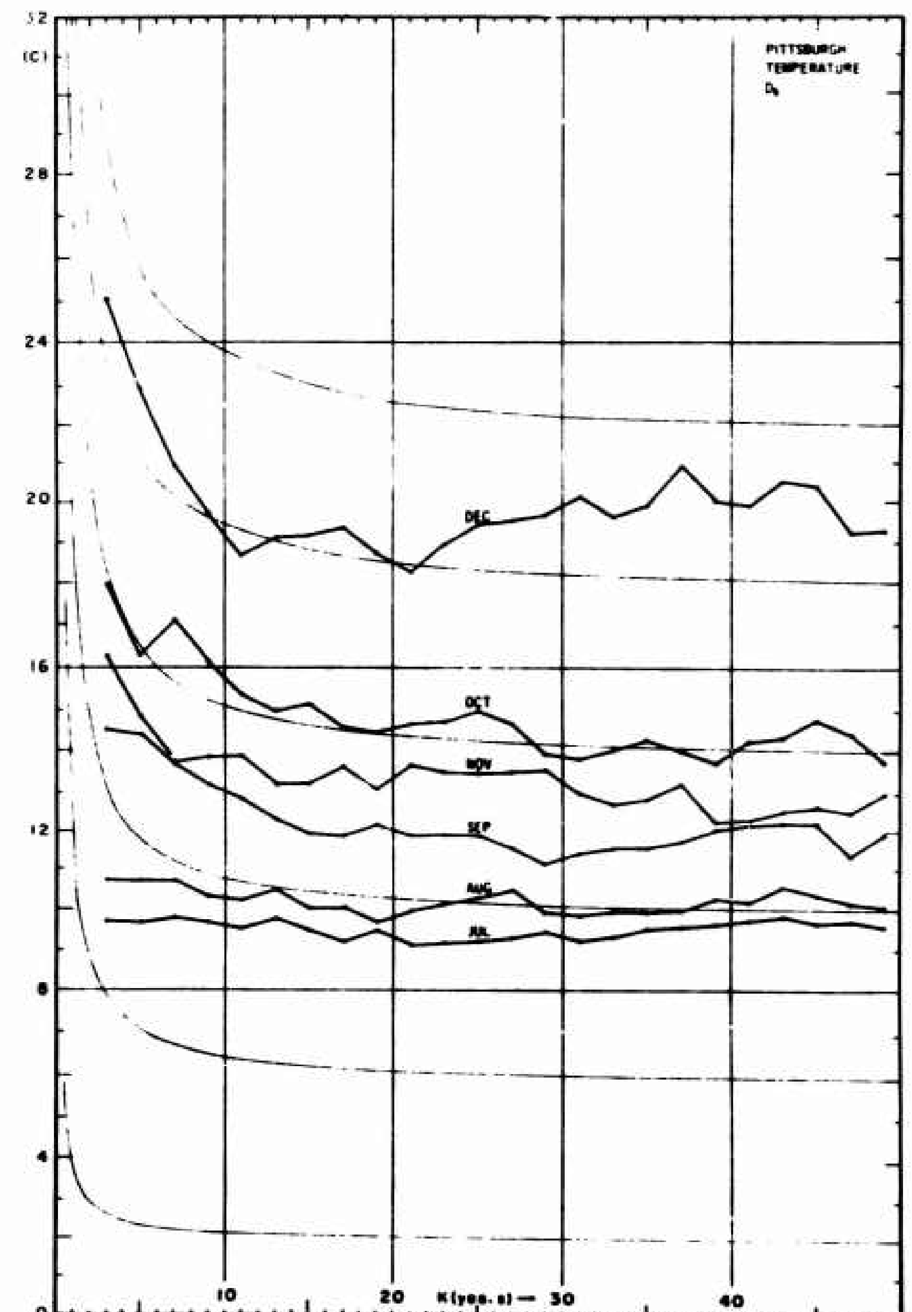


FIGURE 15D

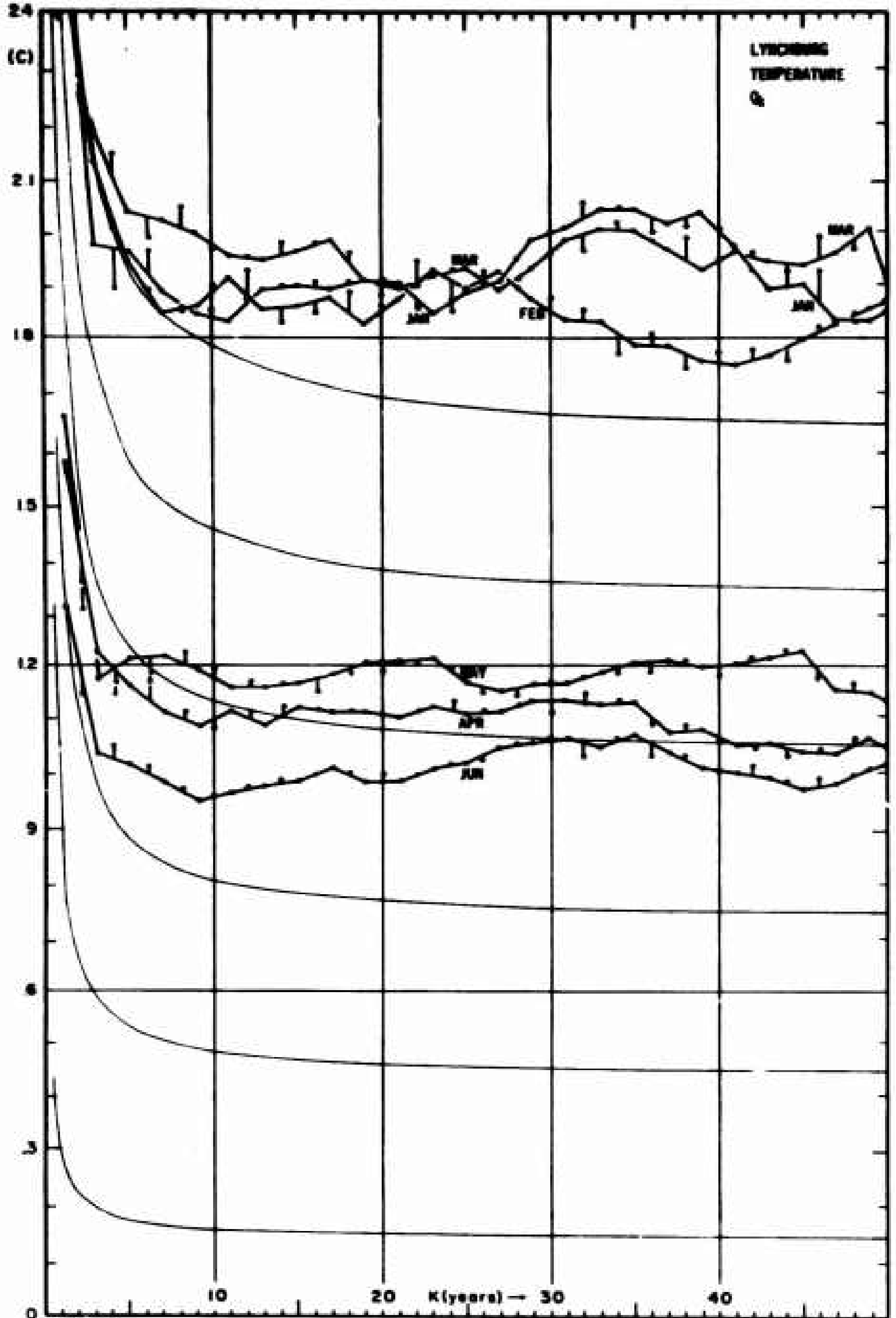


FIGURE 16A

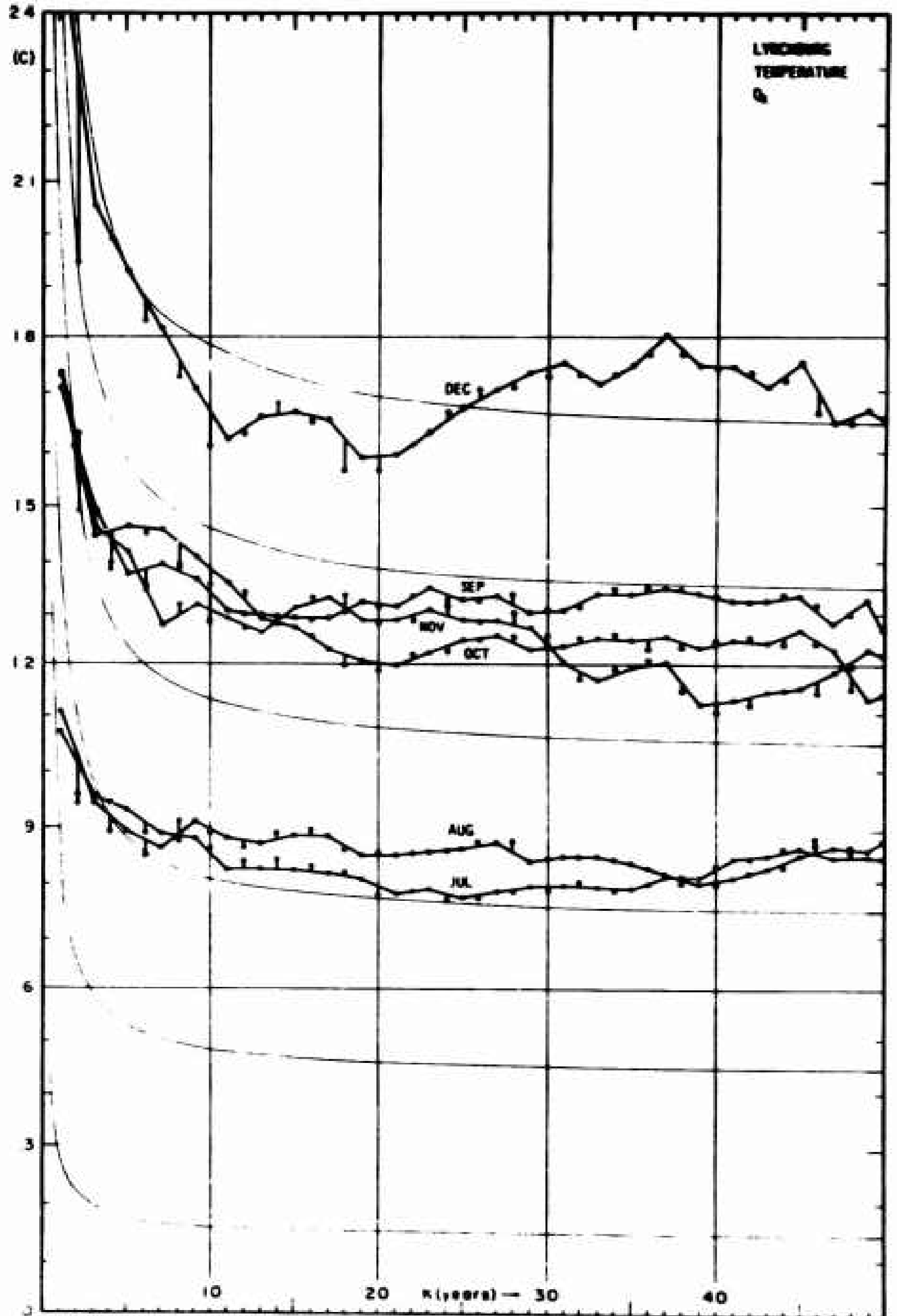


FIGURE 16B

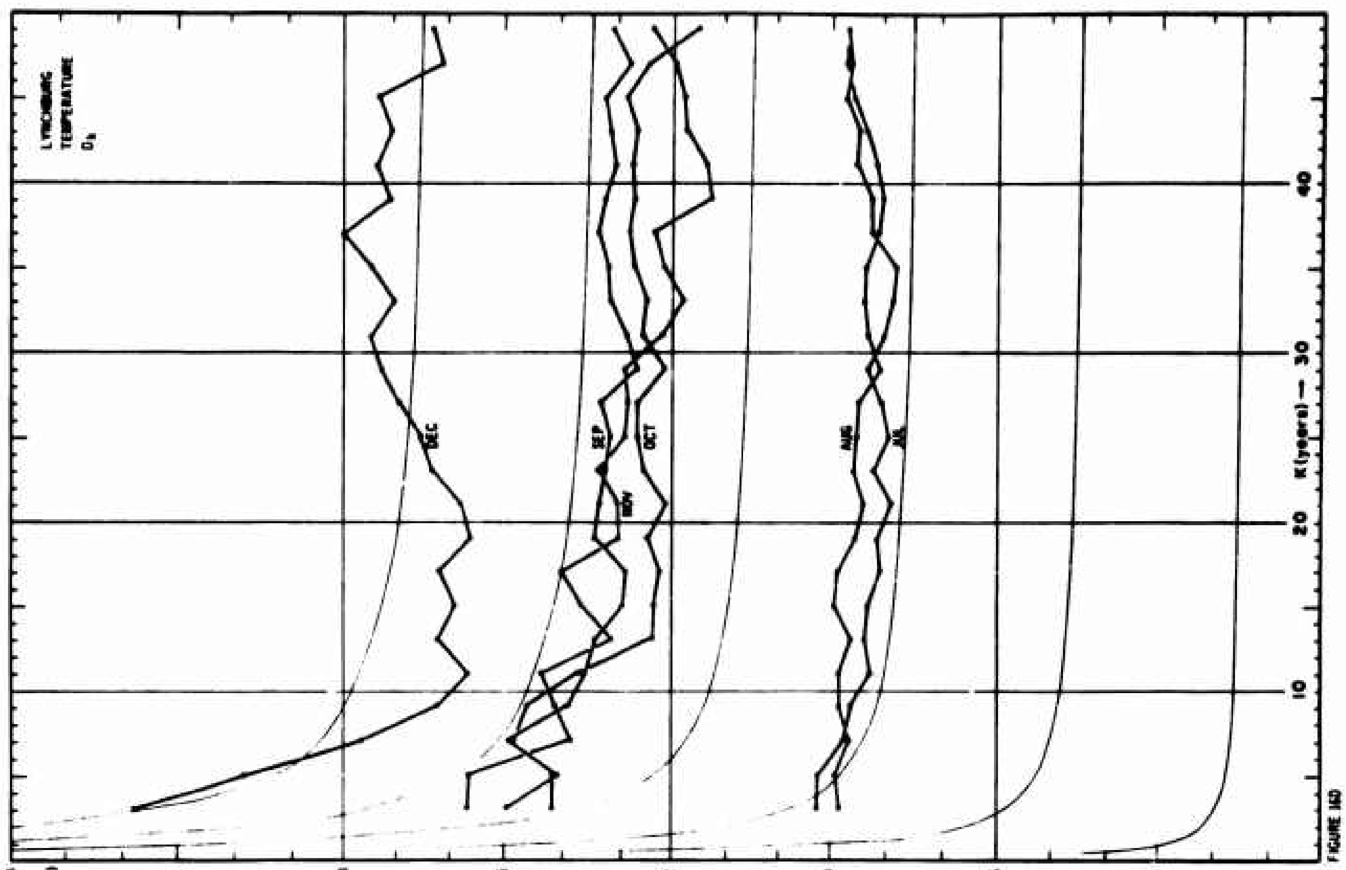


FIGURE 16D

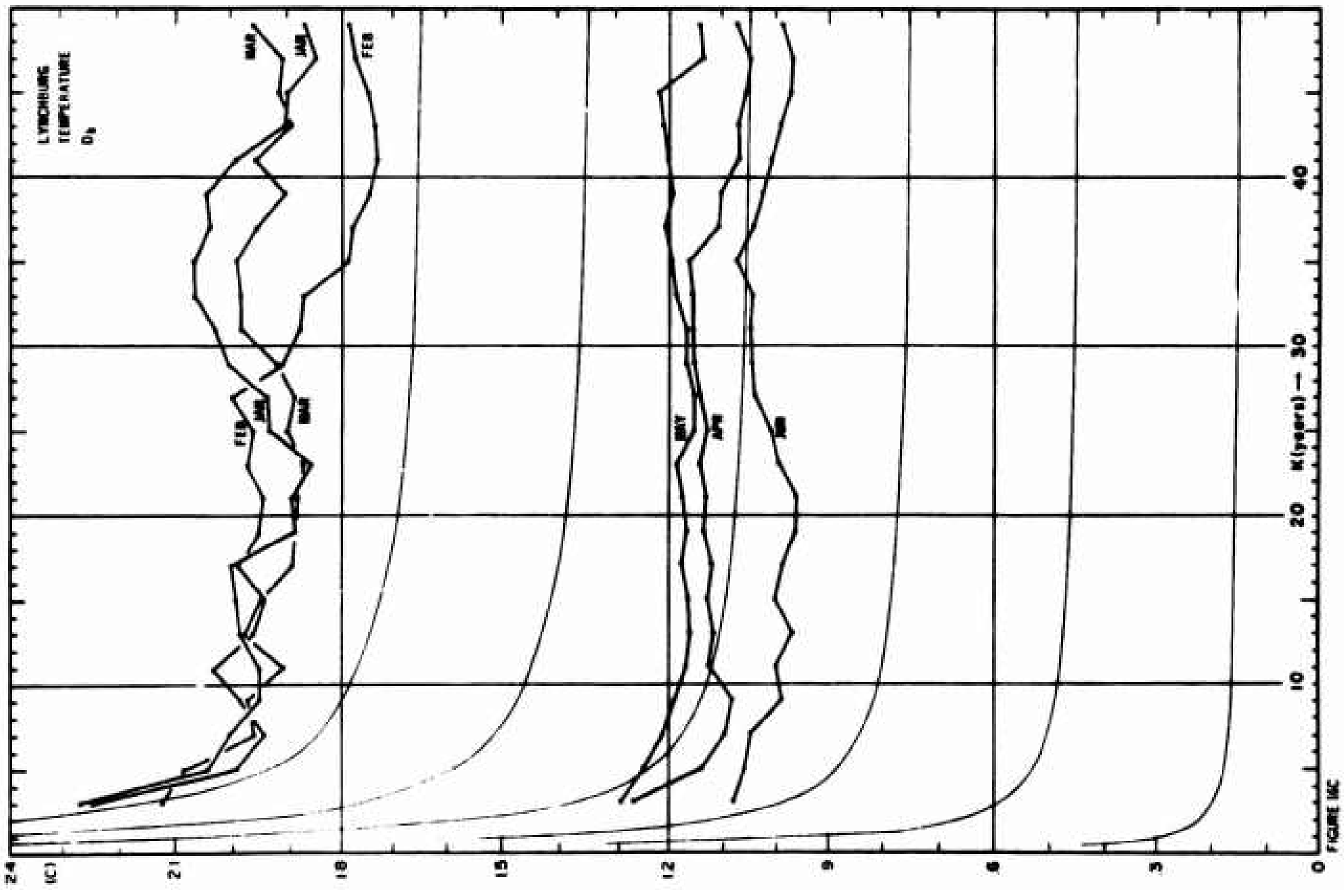


FIGURE 16C

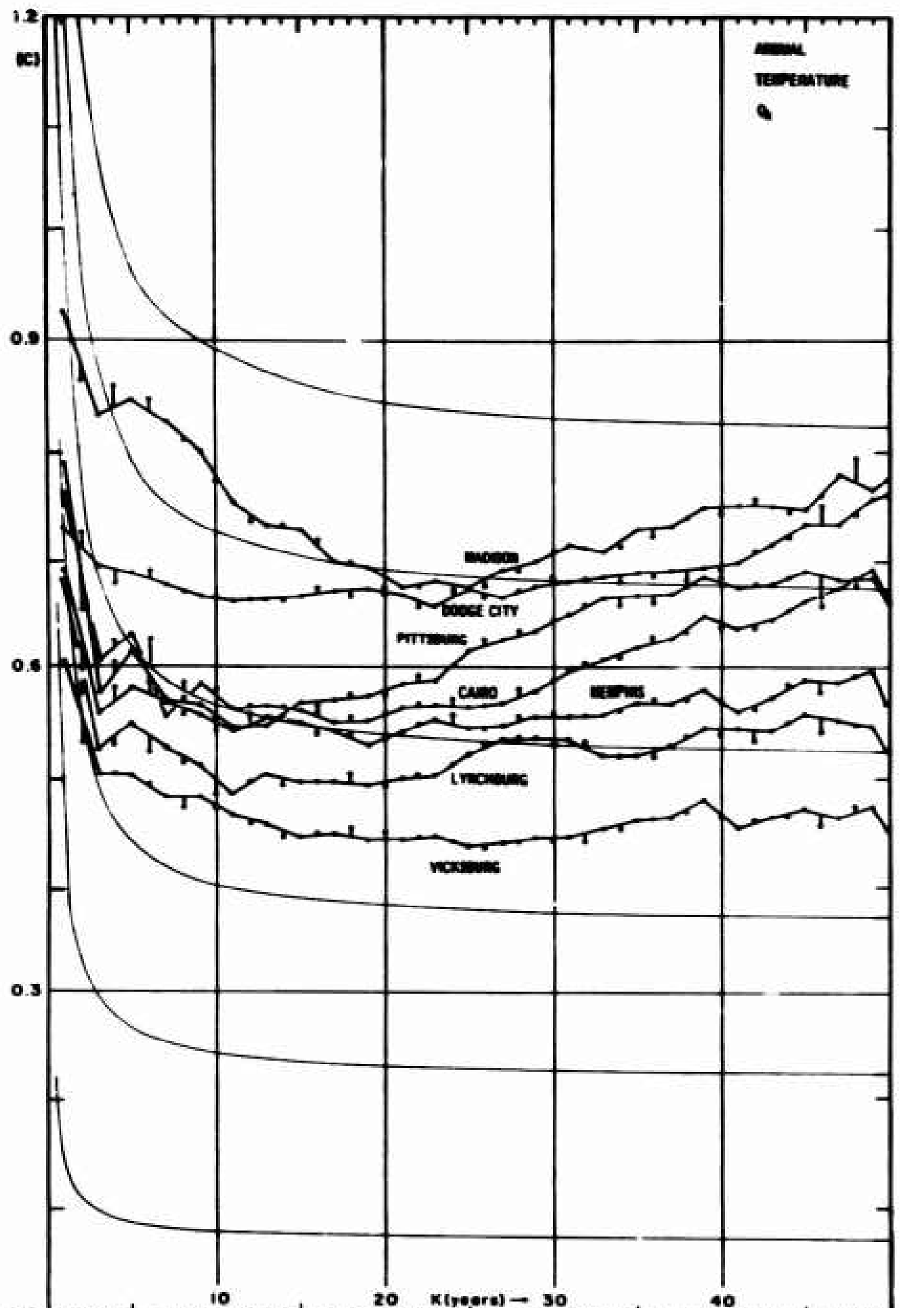


FIGURE 17A

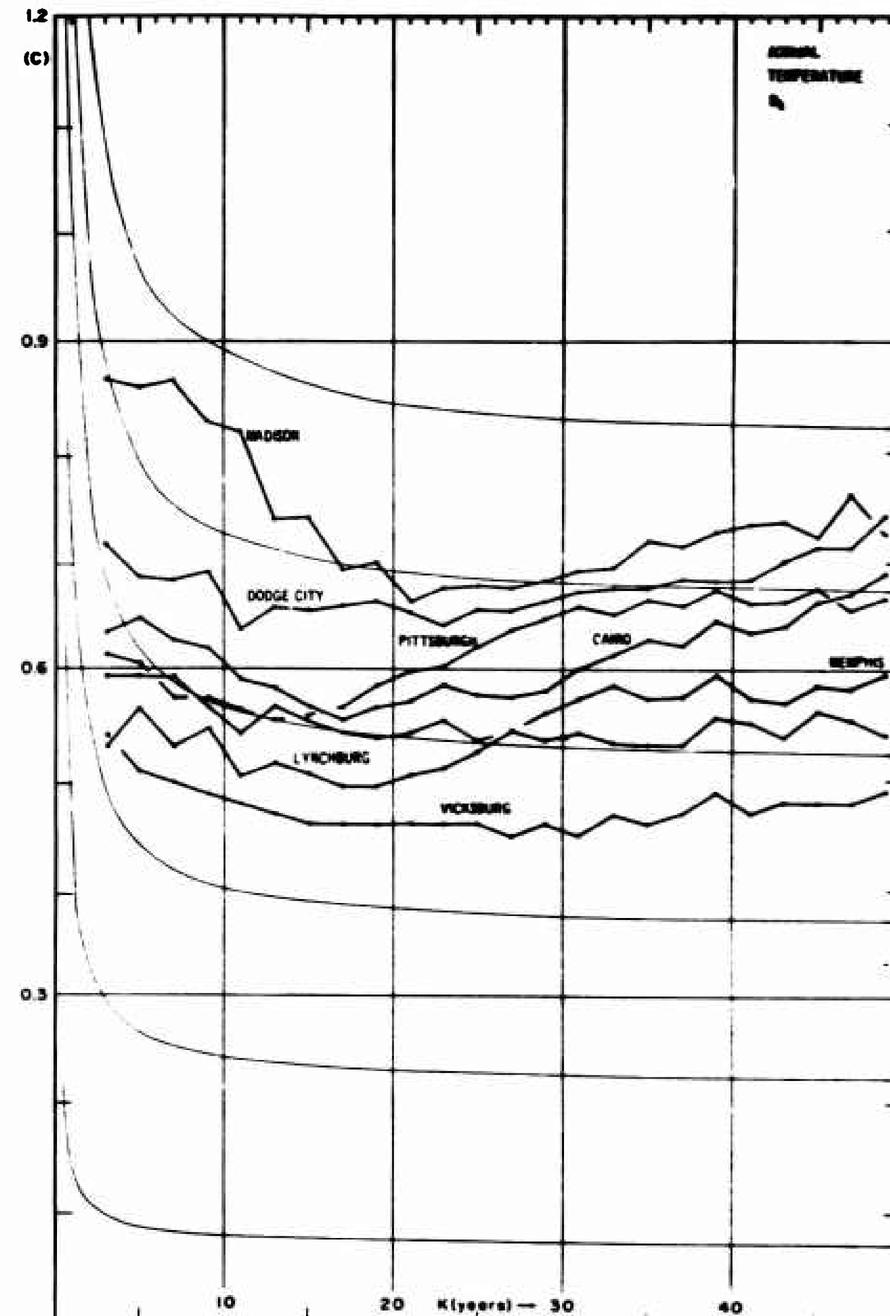


FIGURE 17B

Figures exhibiting the behavior of precipitation series at seven U.S. stations

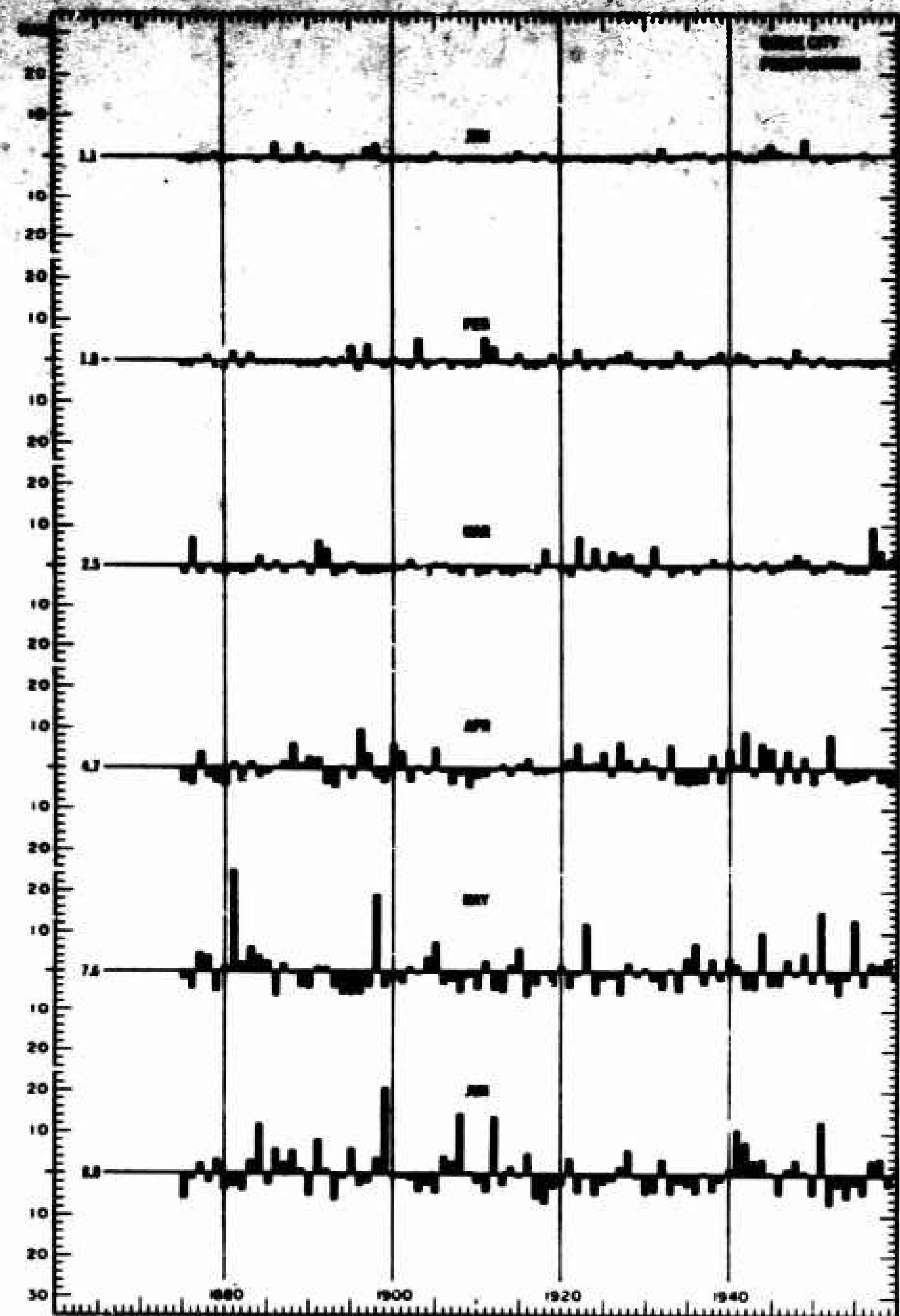


FIGURE [illegible]

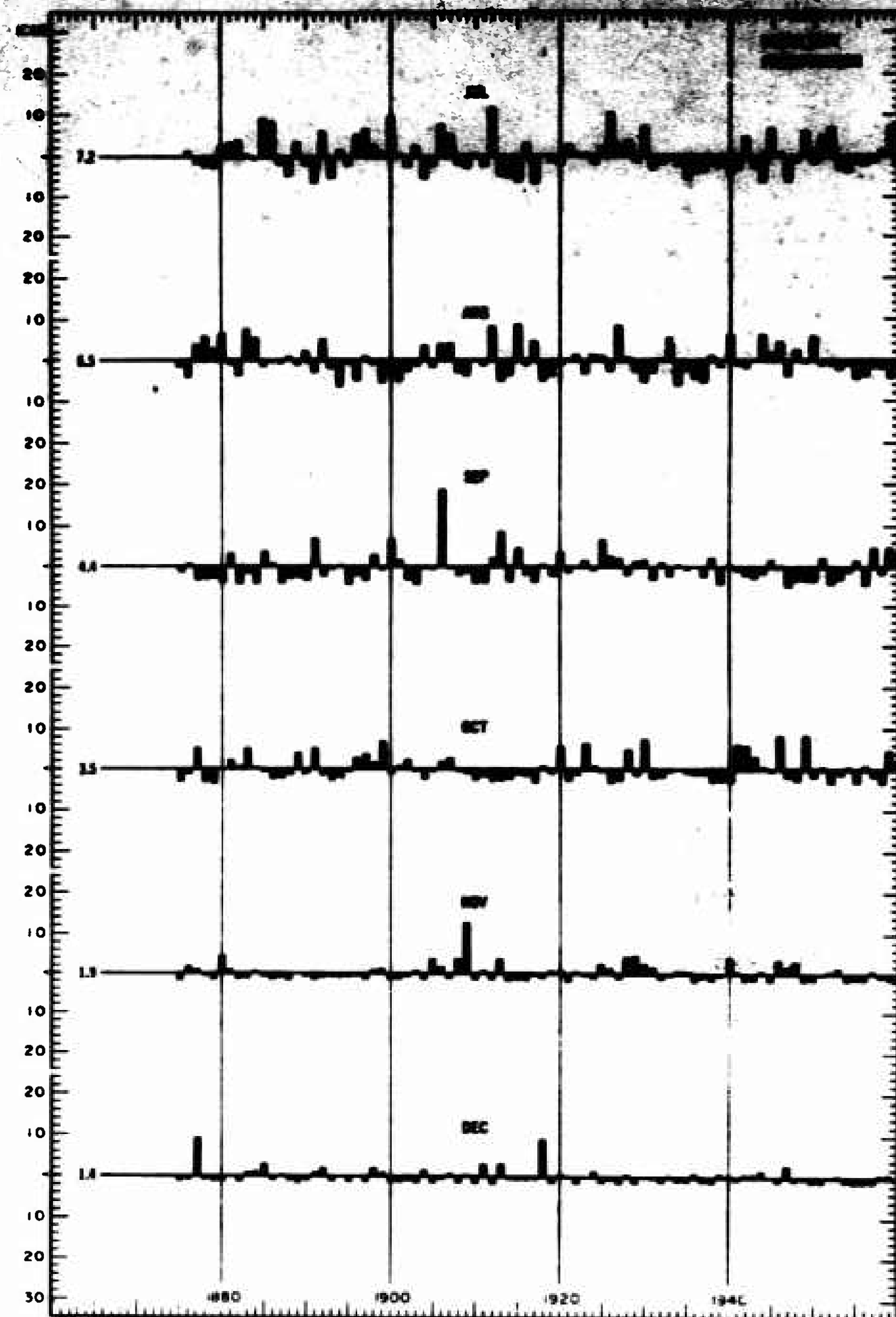


FIGURE [illegible]

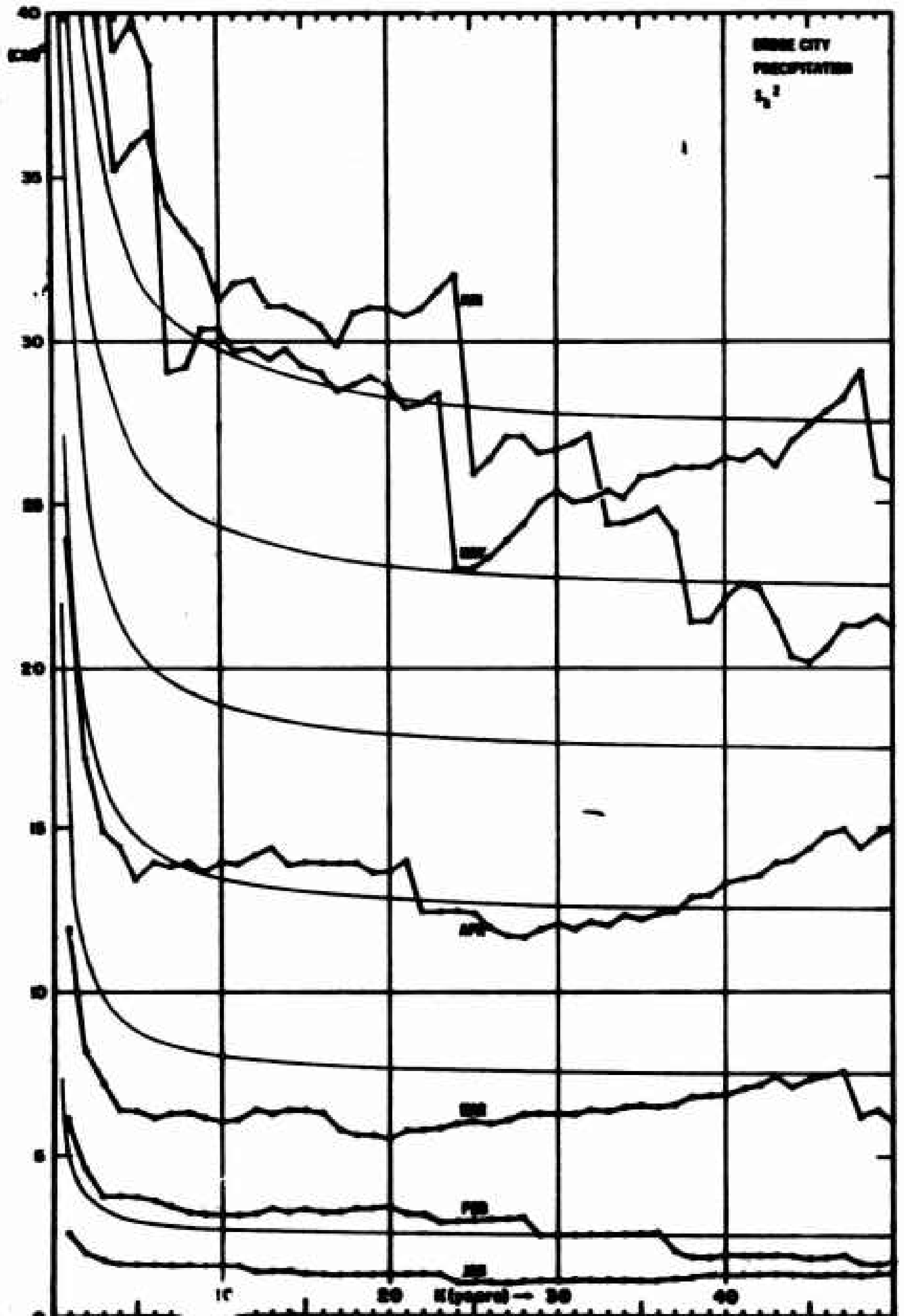


FIGURE 3C

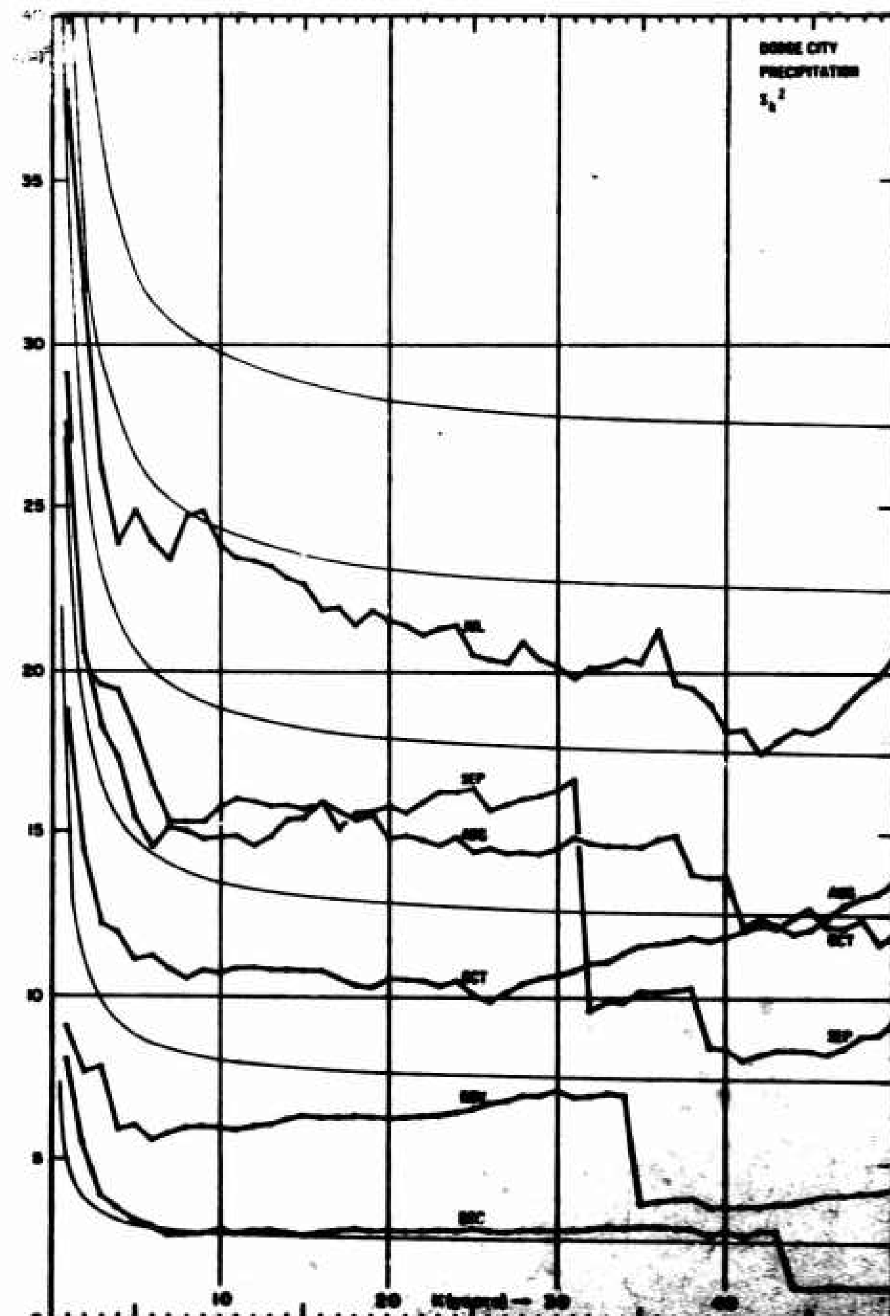


FIGURE 3D

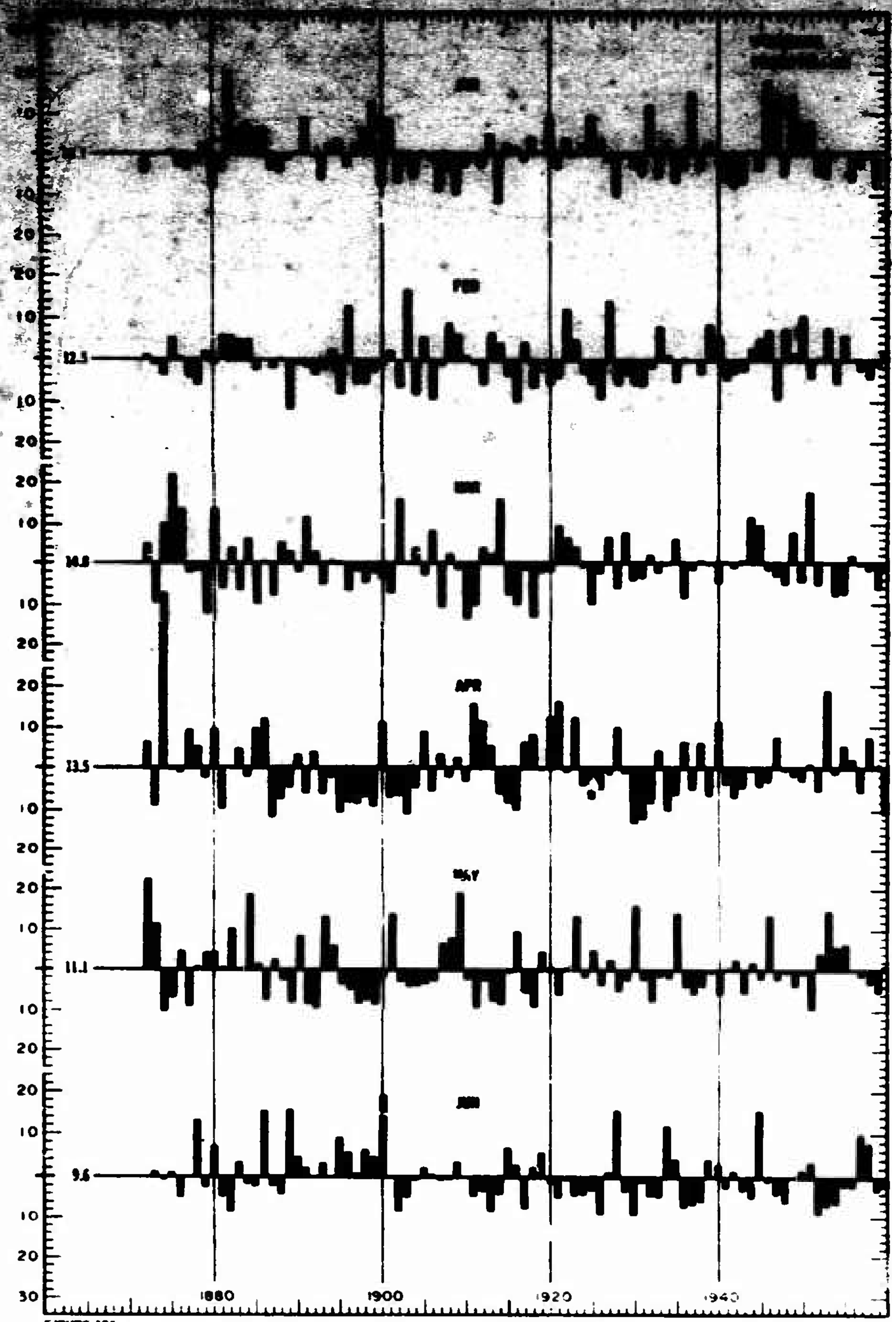


FIGURE 19A

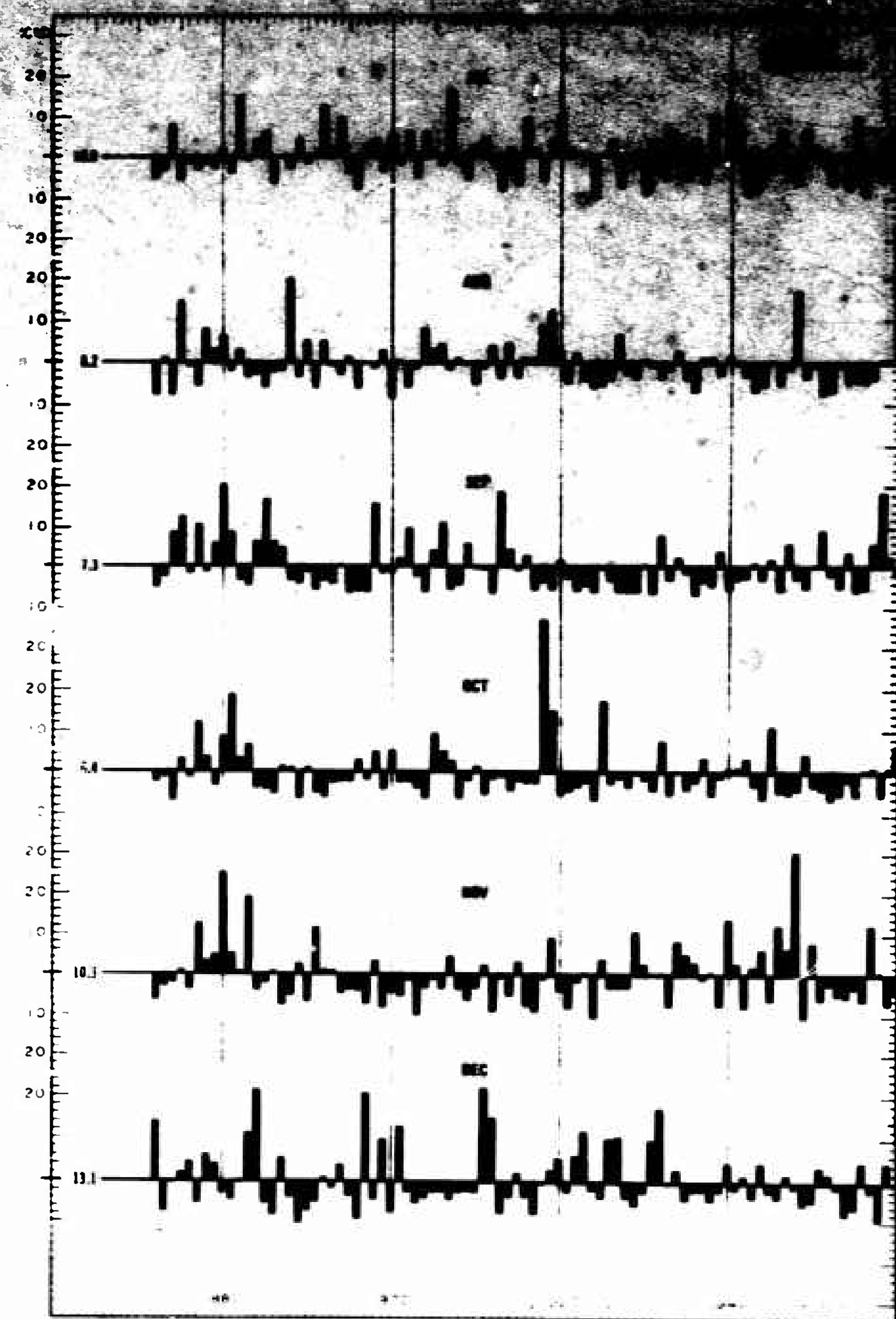


FIGURE 19B

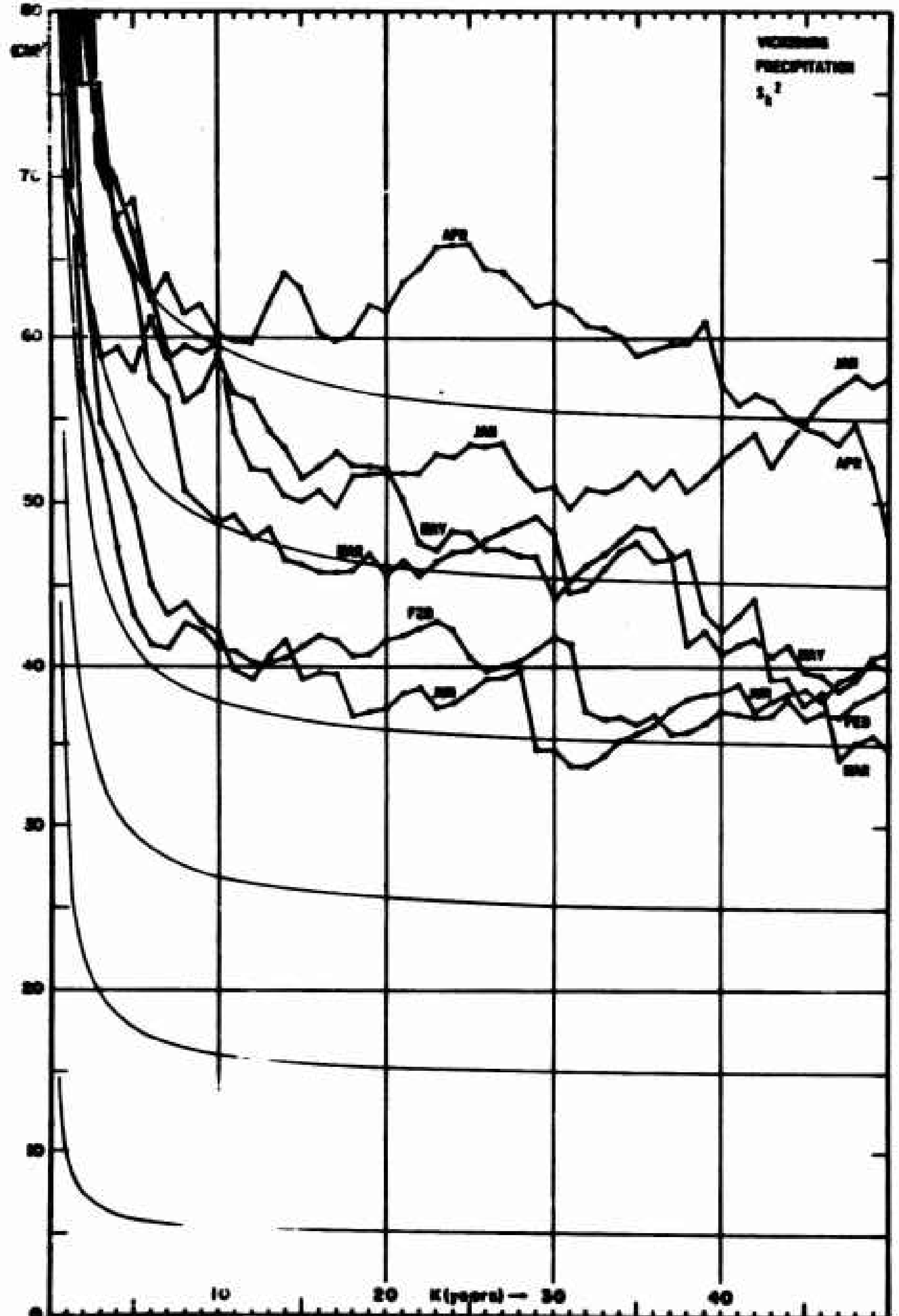


FIGURE 20C

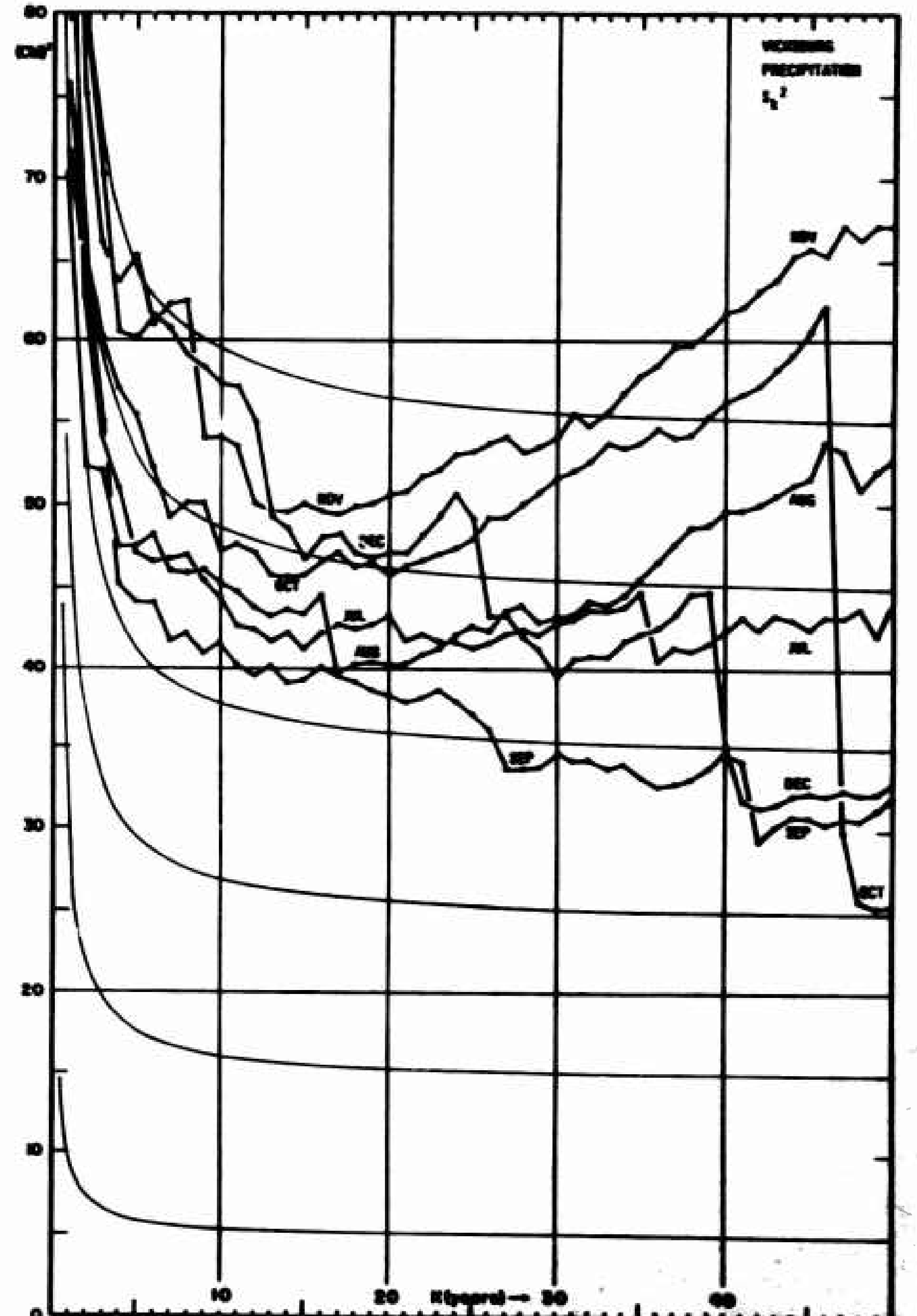


FIGURE 20D

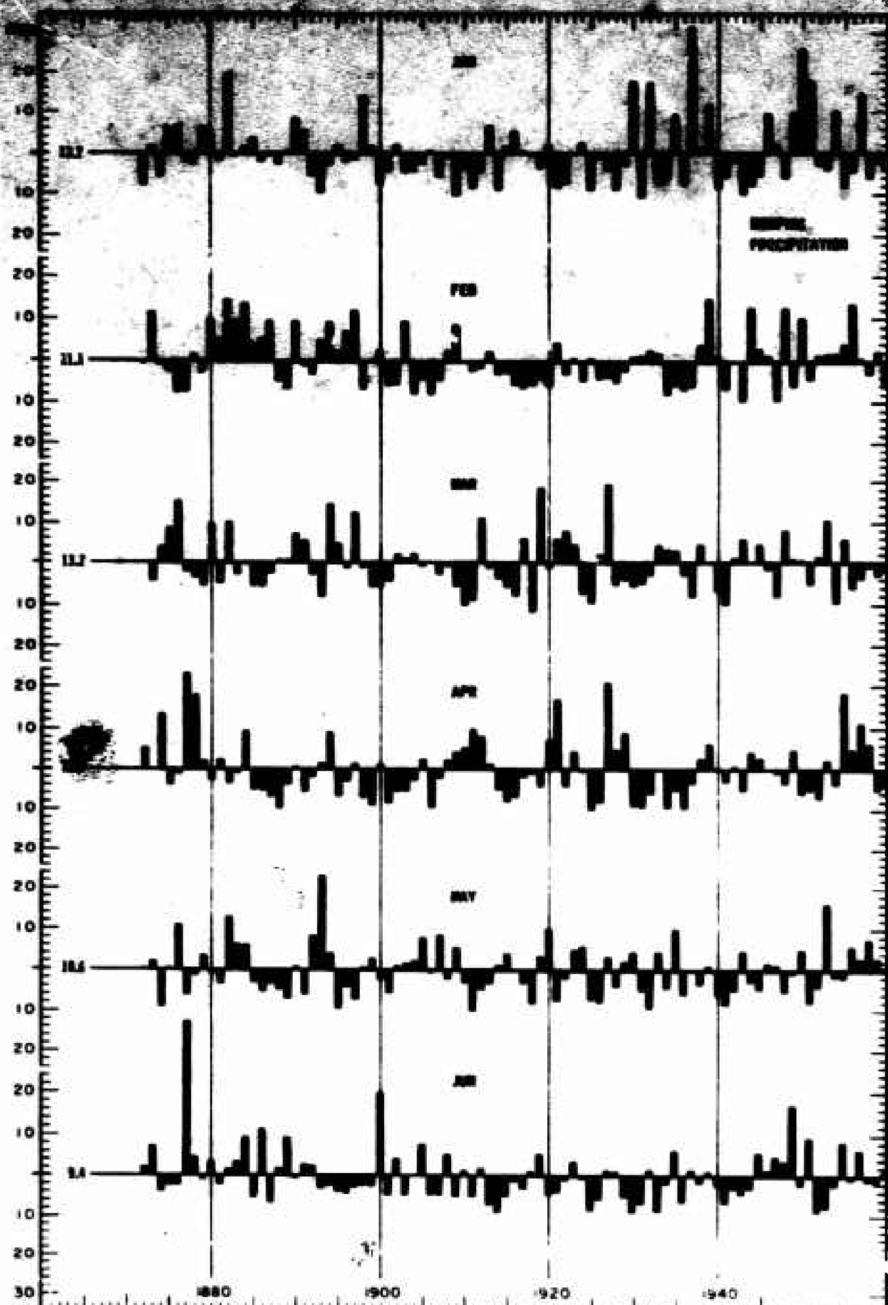


FIGURE 29A

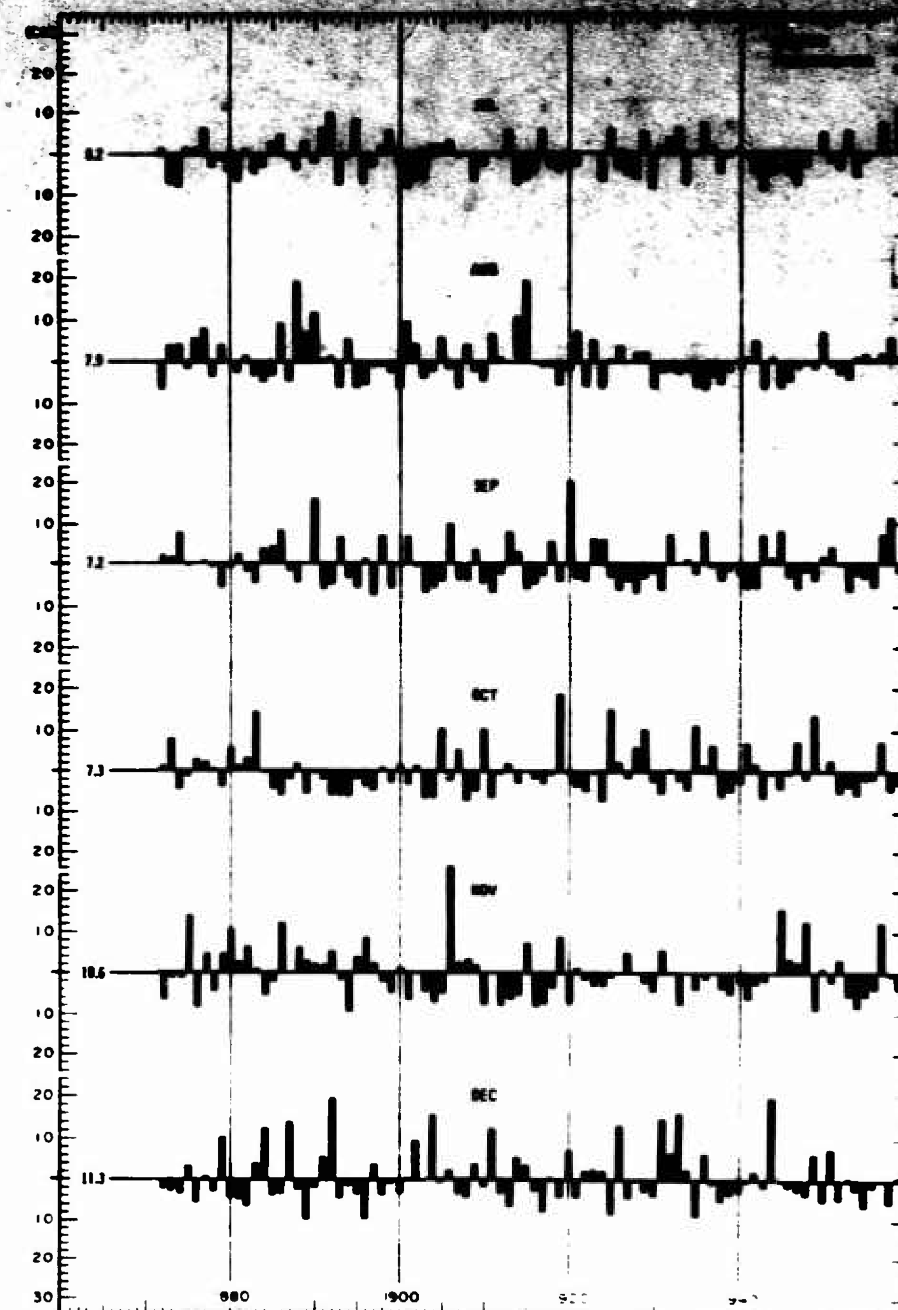
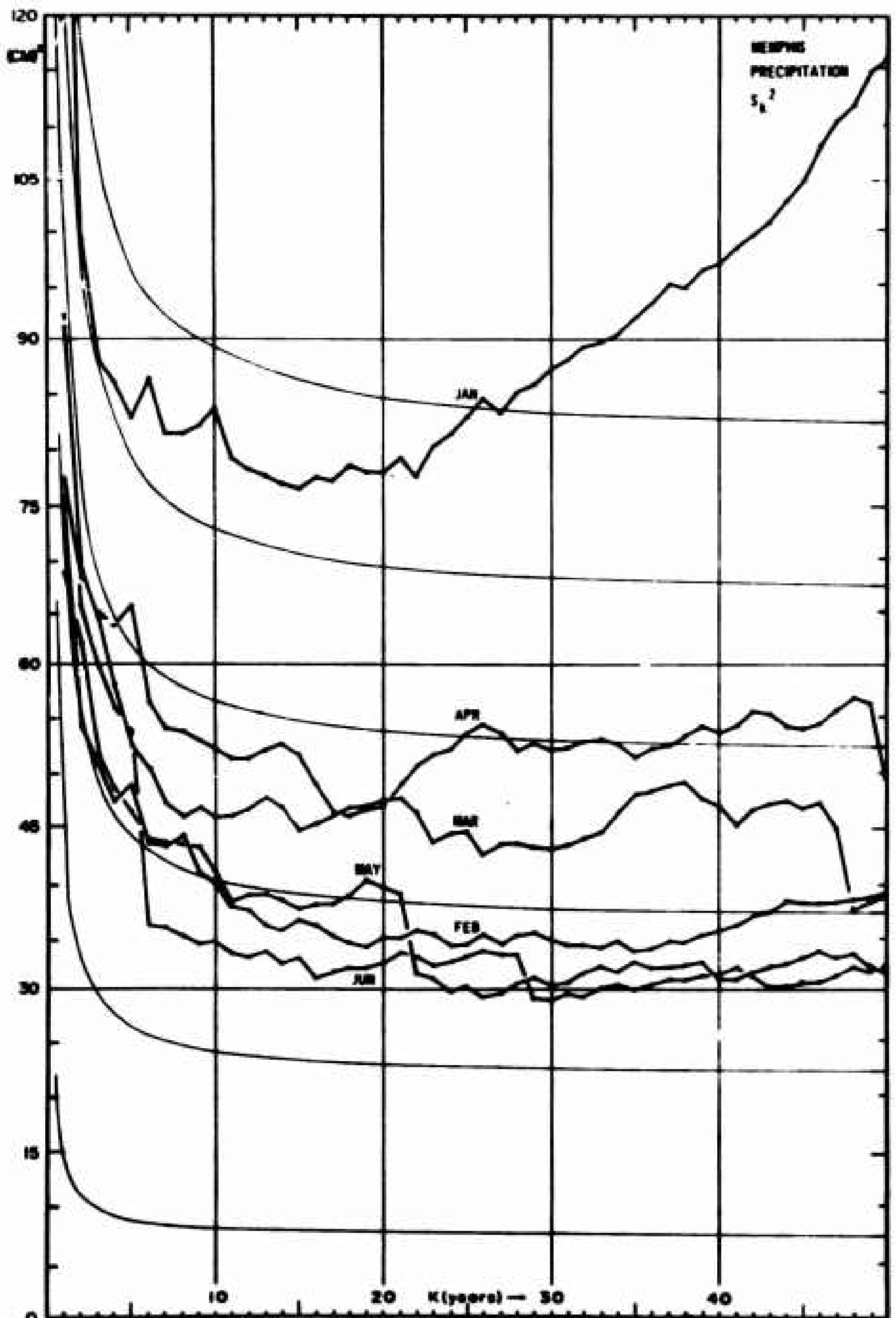
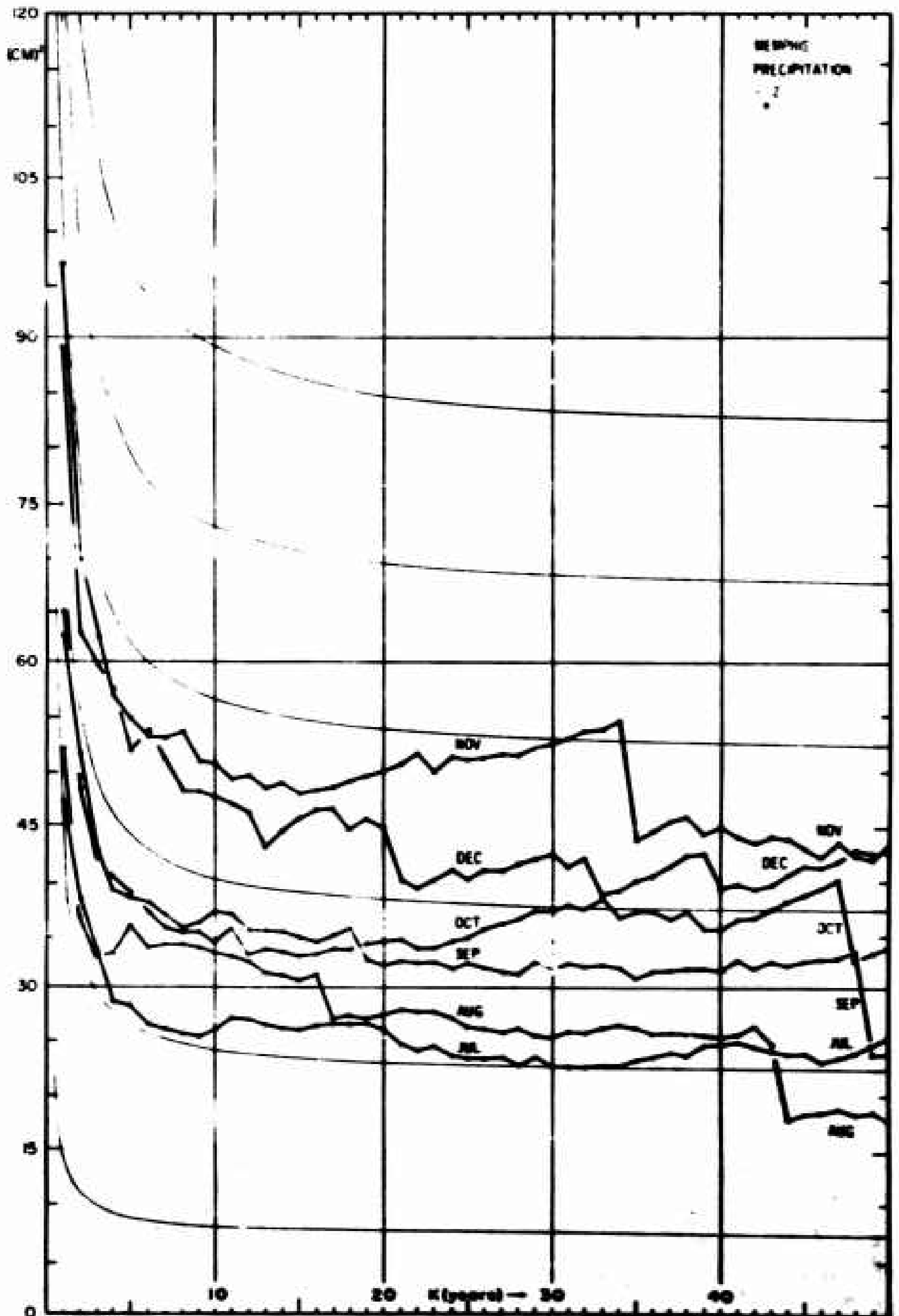


FIGURE 29B



MEMPHIS
PRECIPITATION
S_k^2
120
(CM)²
105
90
75
60
45
30
15
0
10
20
K(years) — 30
40
JAN
APR
MAR
MAY
FEB
JUN

FIGURE 20C



MEMPHIS
PRECIPITATION
120
(CM)²
105
90
75
60
45
30
15
0
10
20
K(years) — 30
40
NOV
DEC
OCT
SEP
AUG
JUL

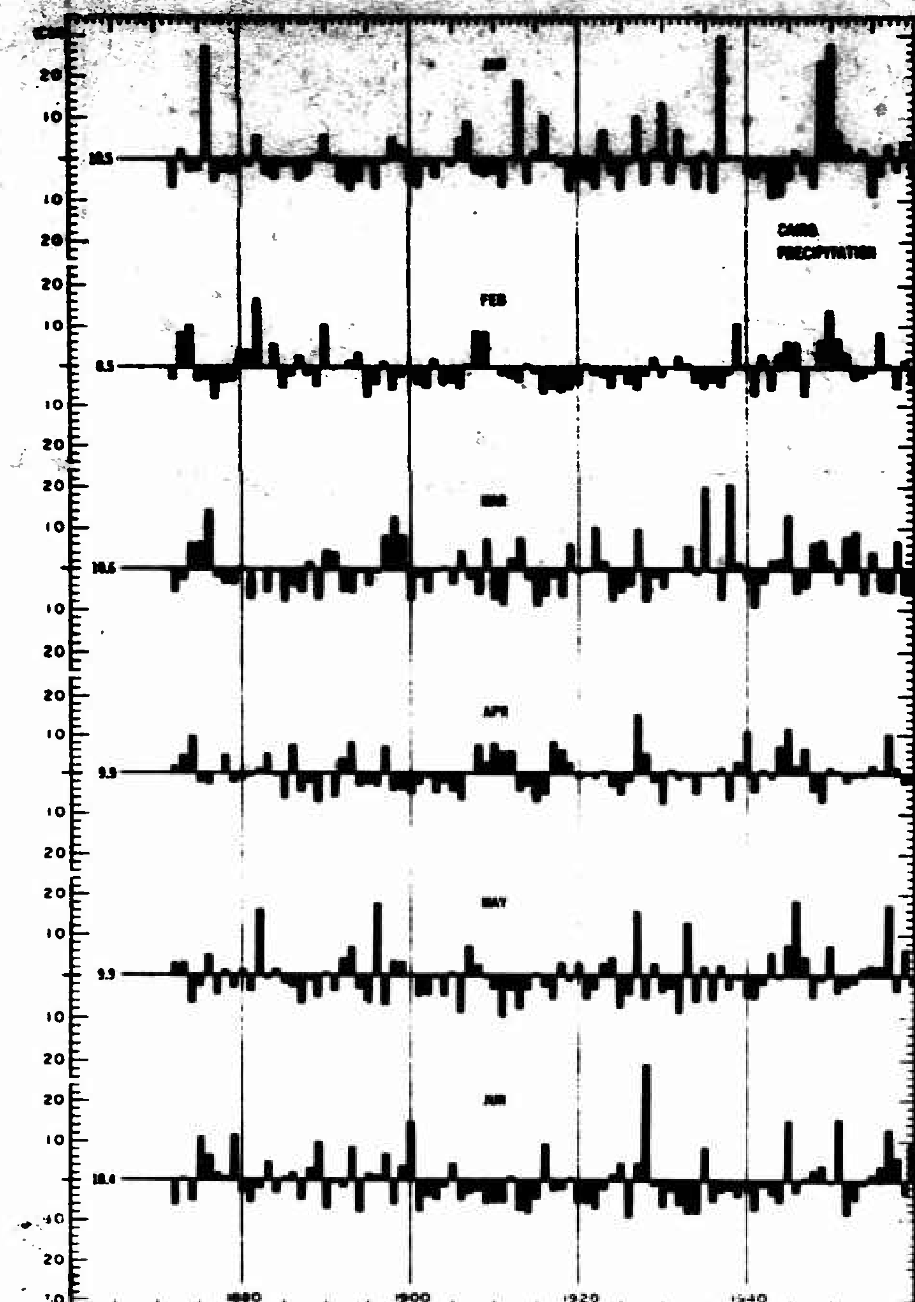


FIGURE 21A

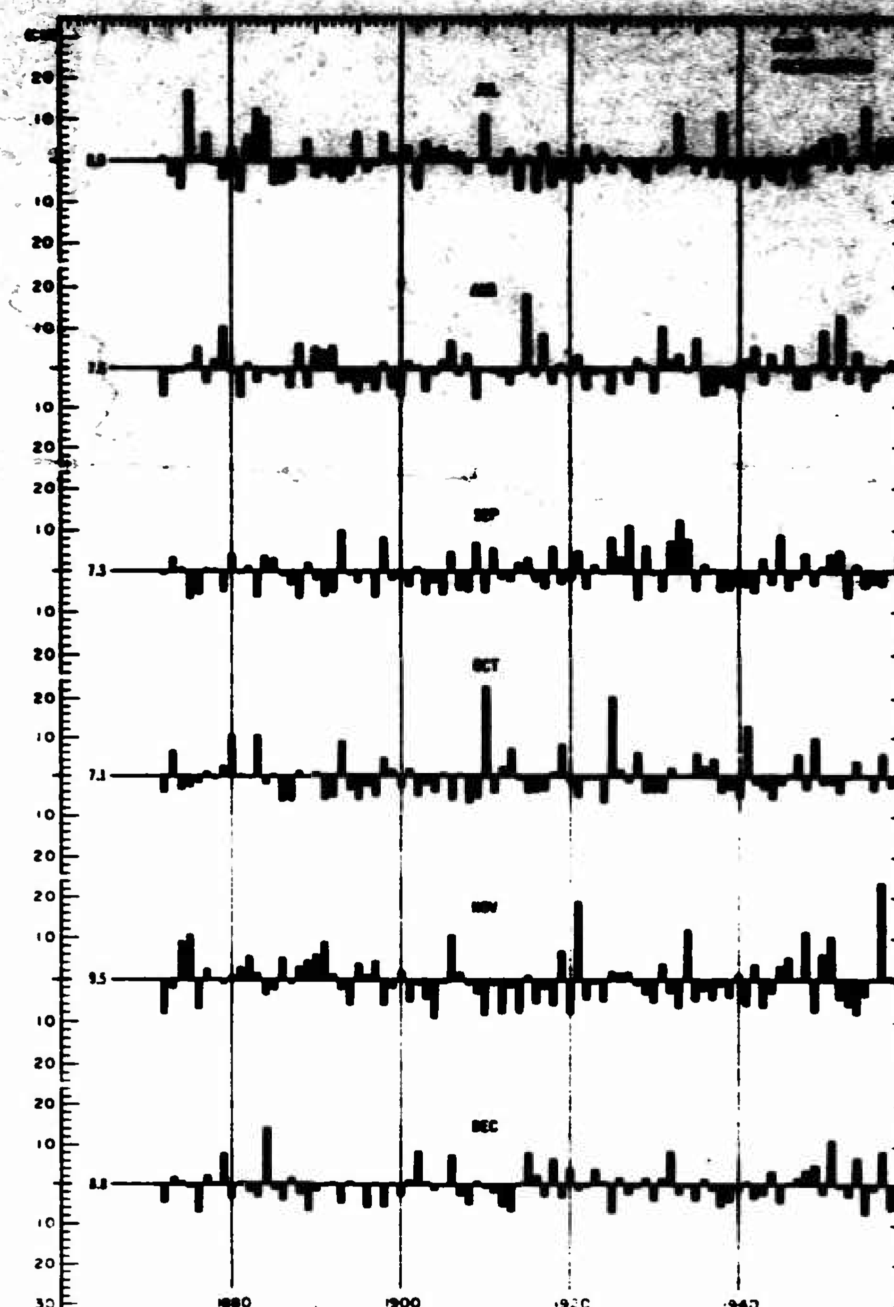


FIGURE 21B

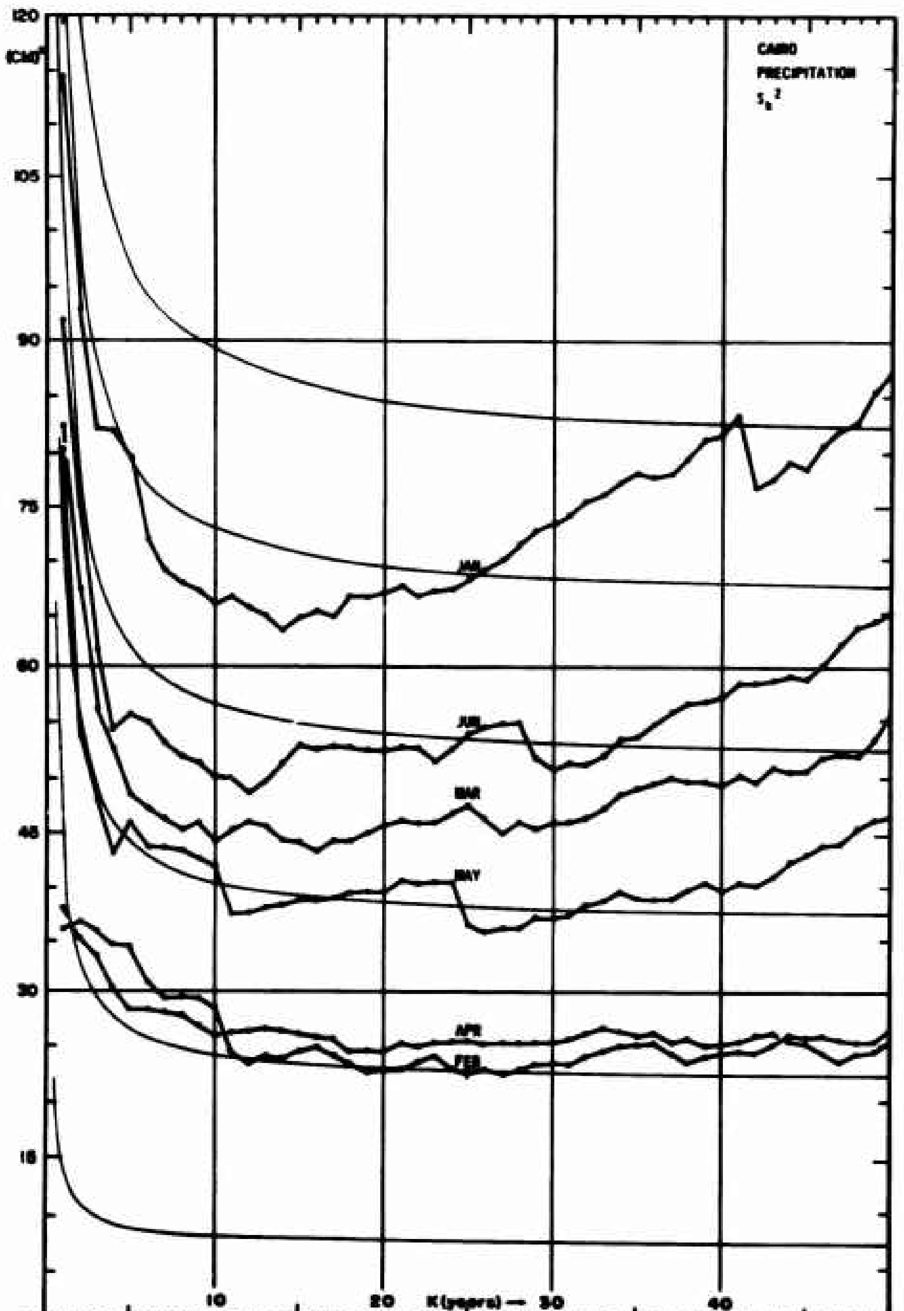


FIGURE 21C

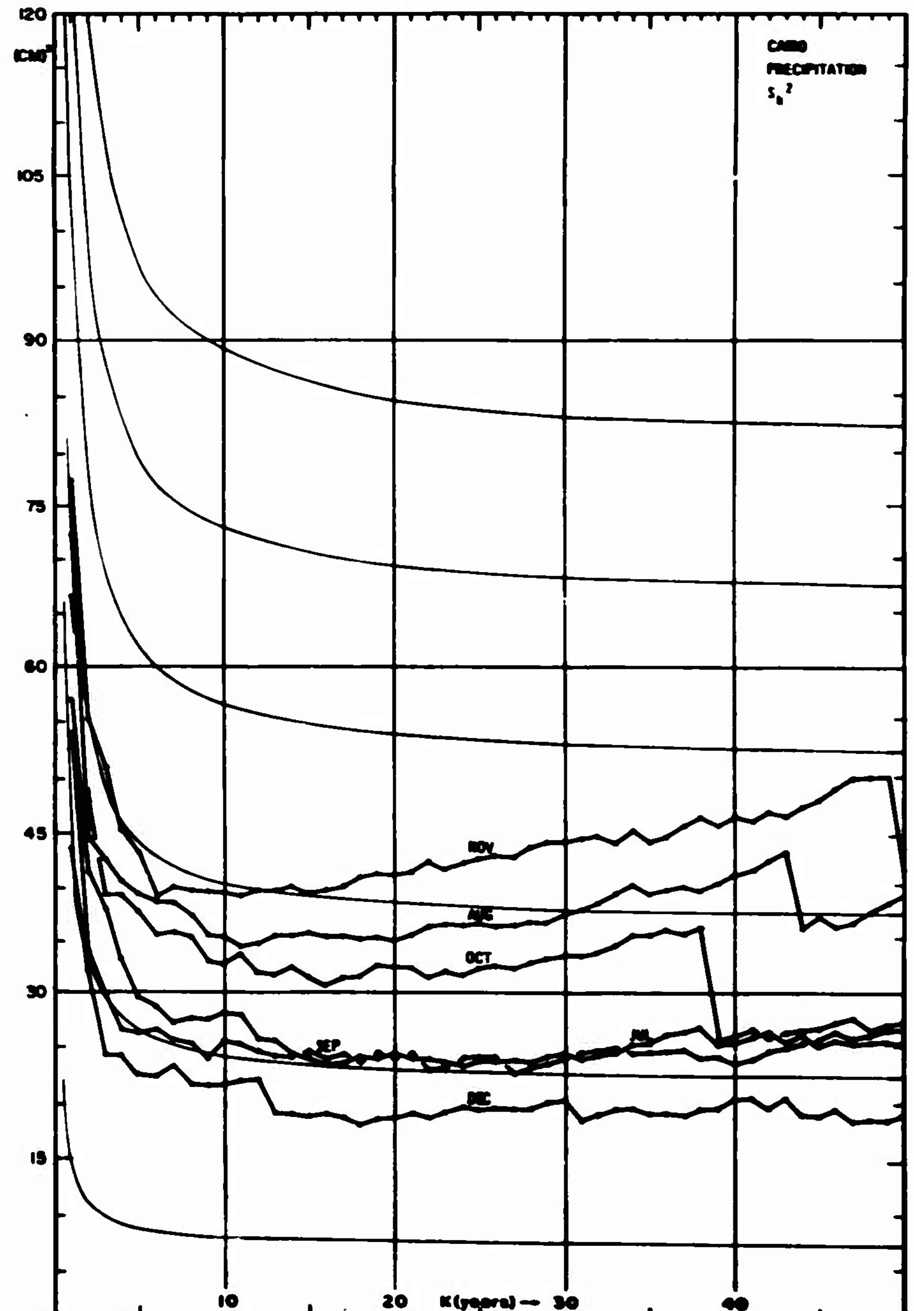


FIGURE 21D

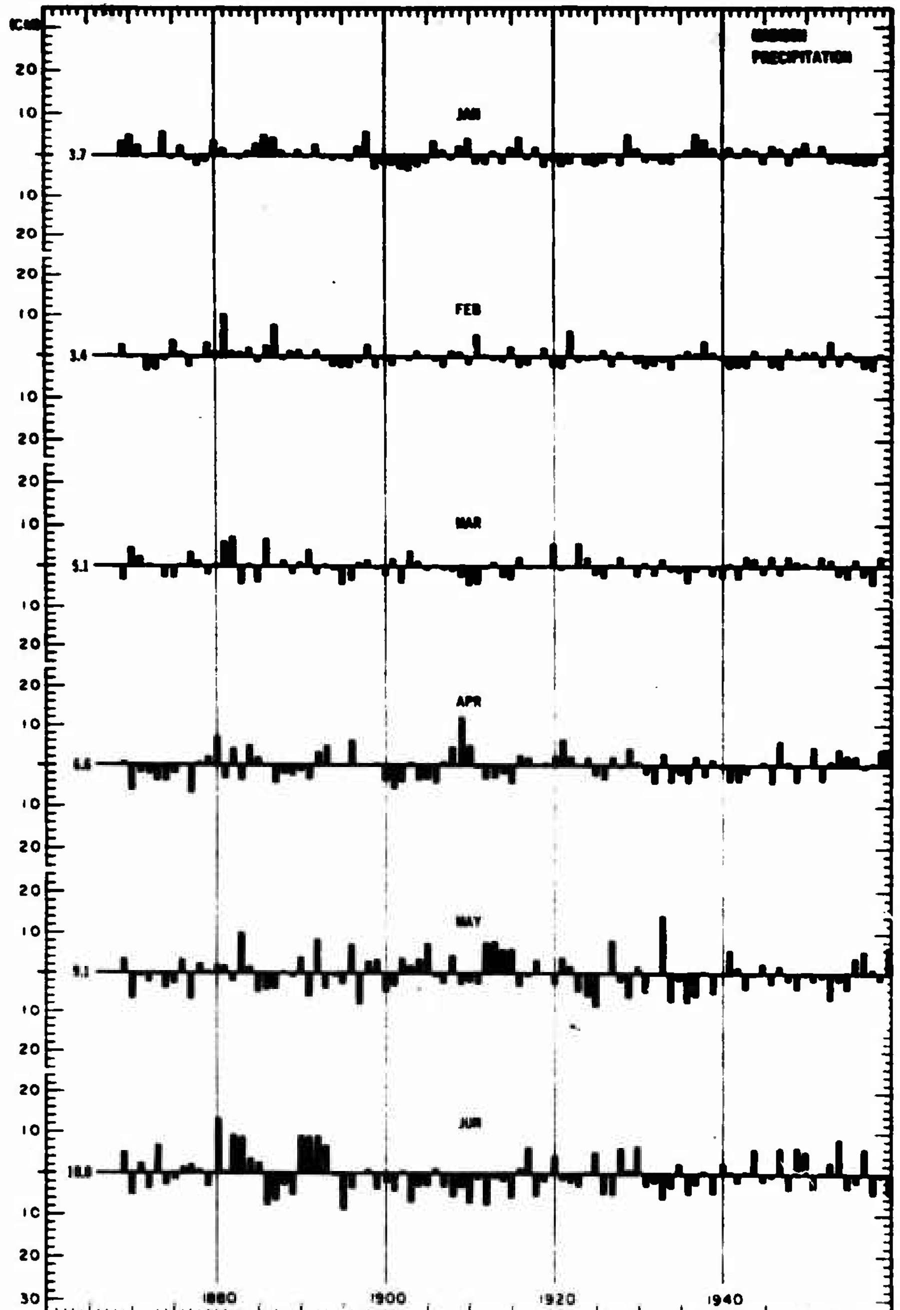


FIGURE 22A

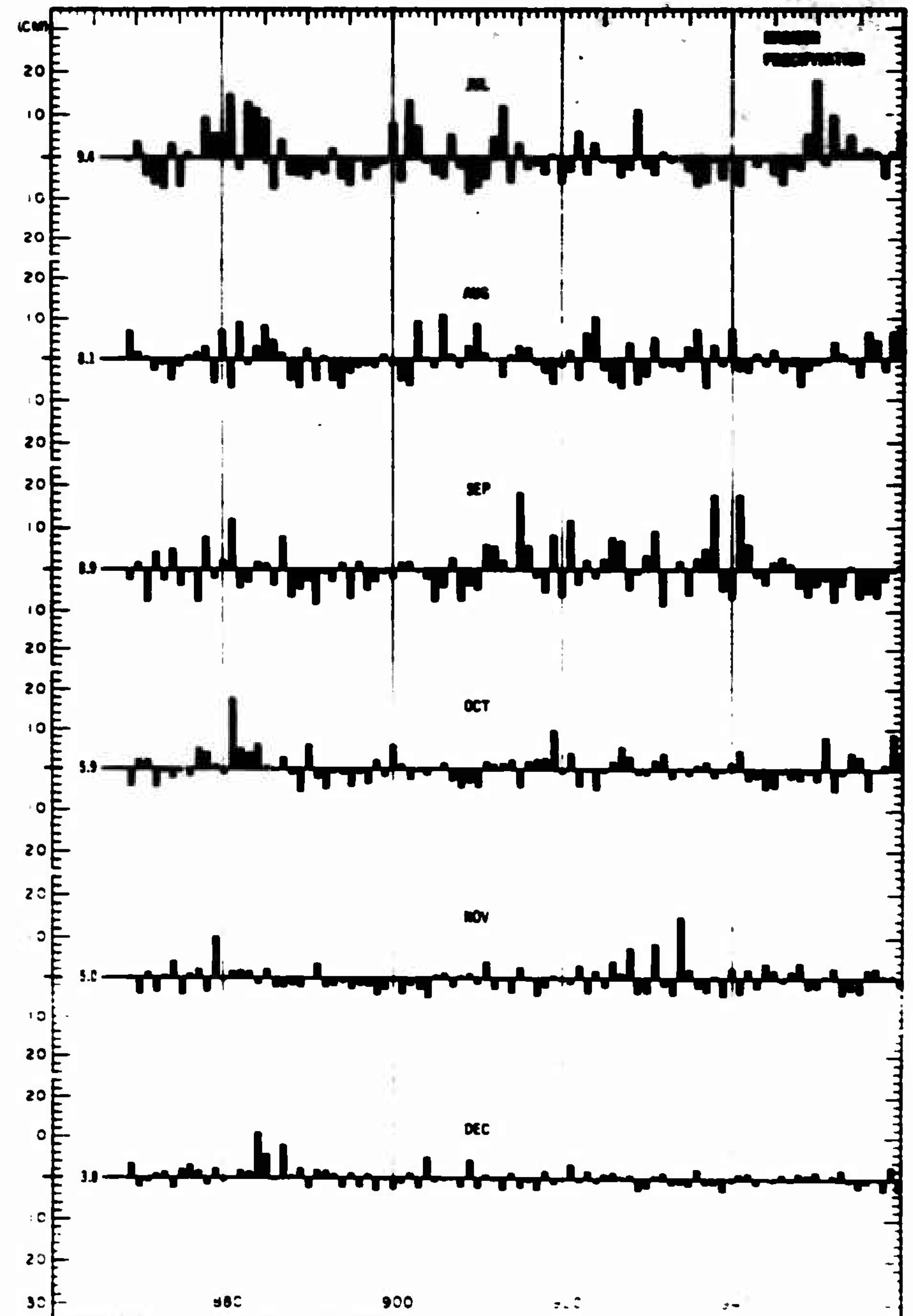


FIGURE 22B

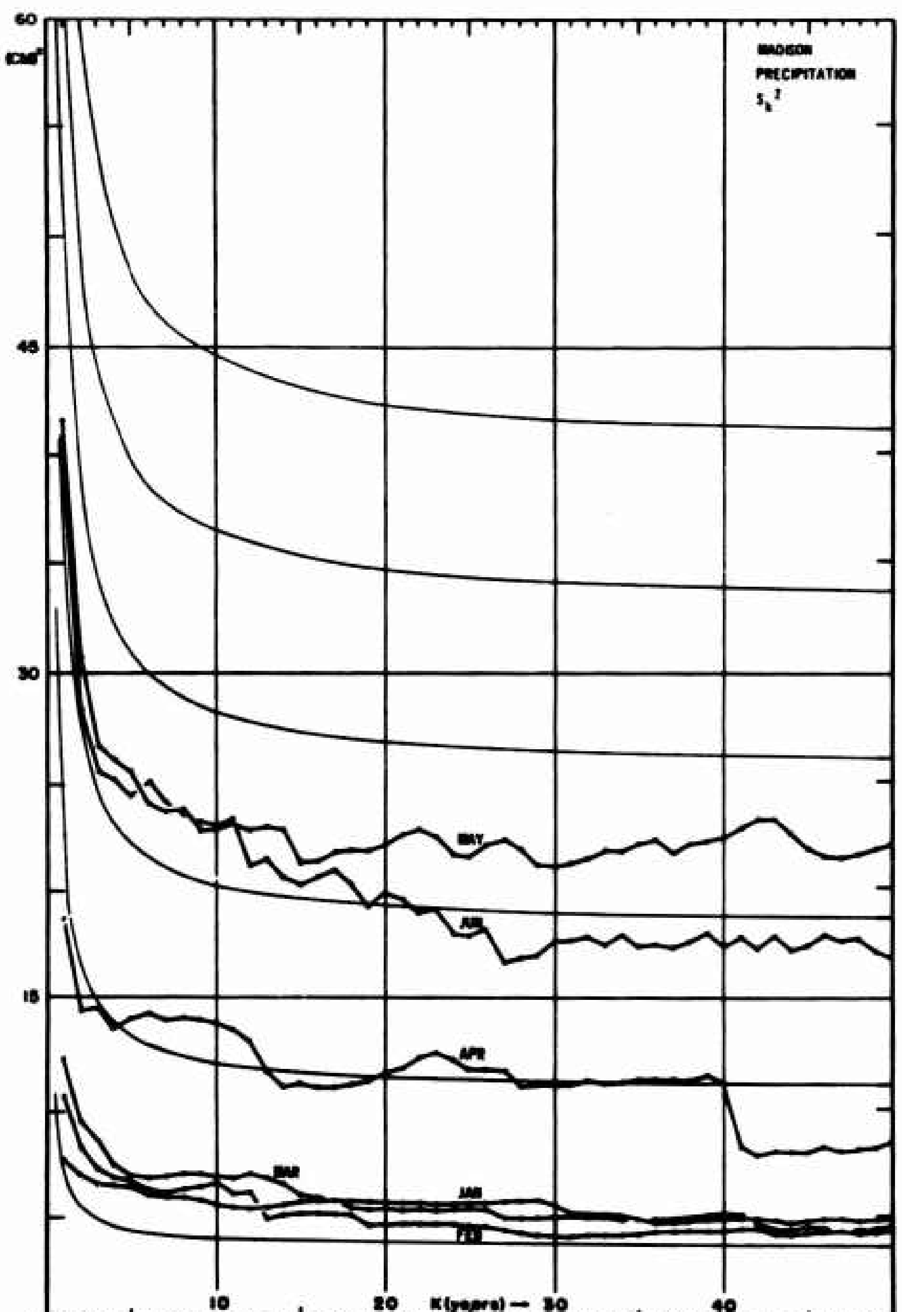


FIGURE 22C

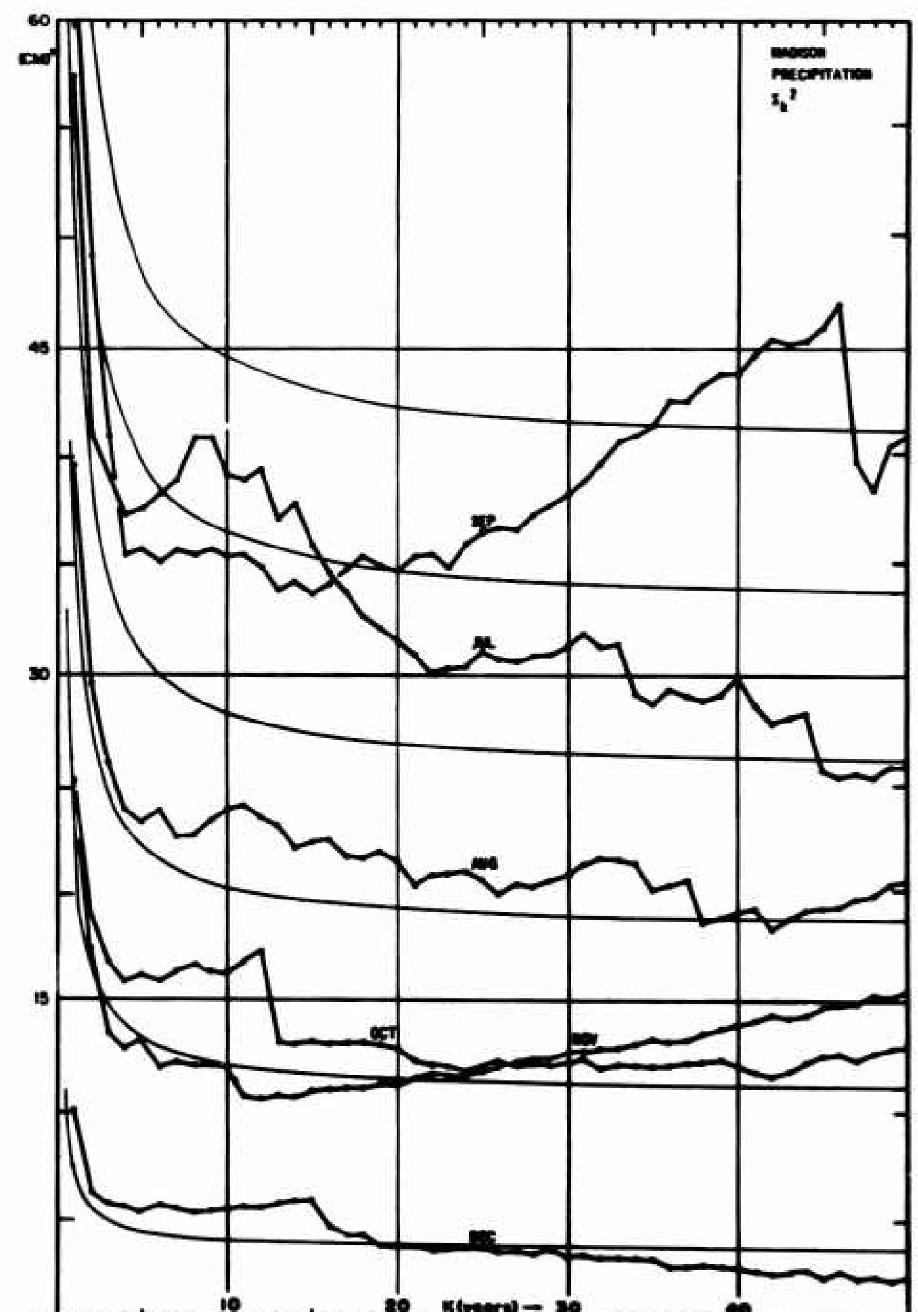


FIGURE 22D

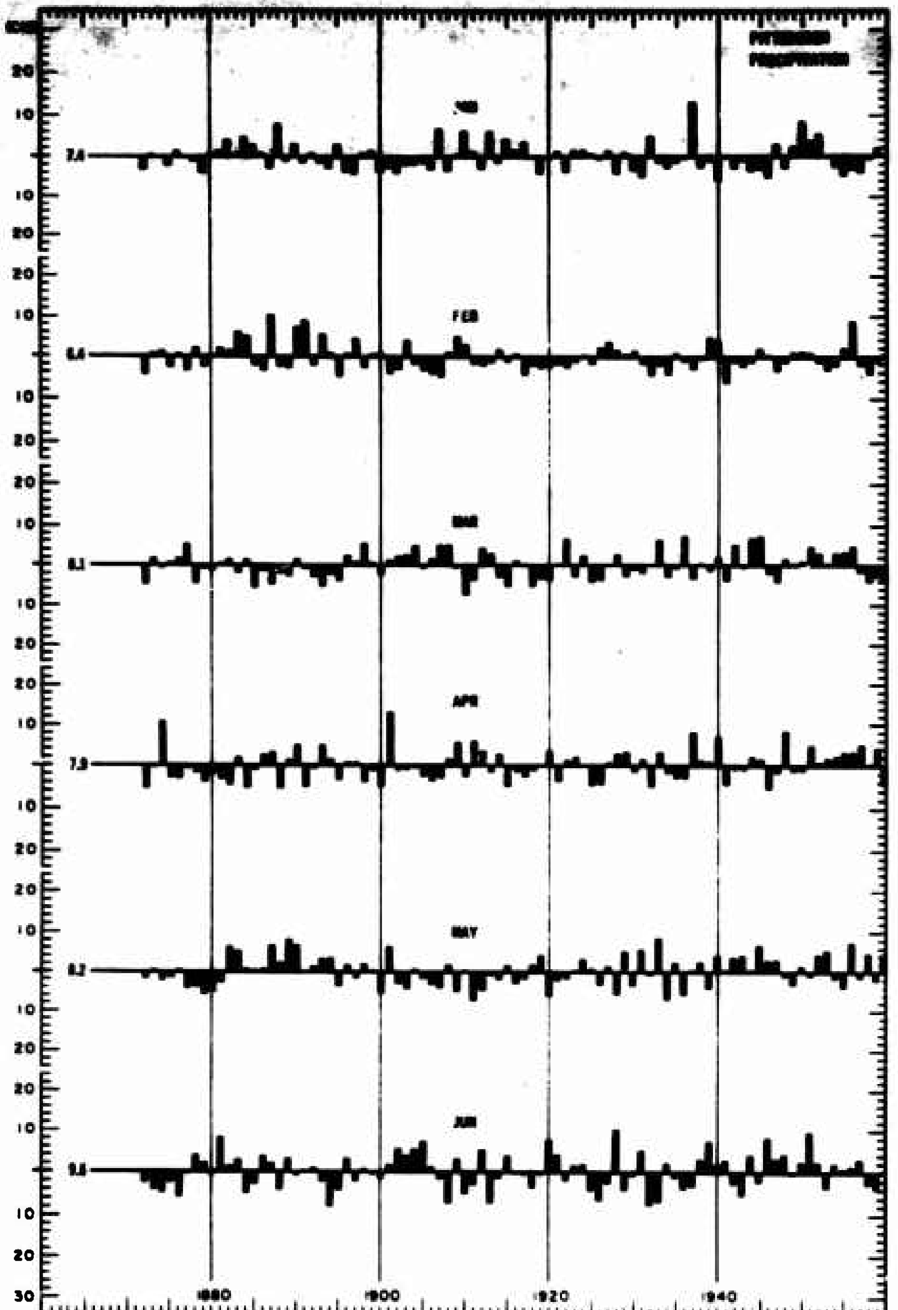


FIGURE 23A

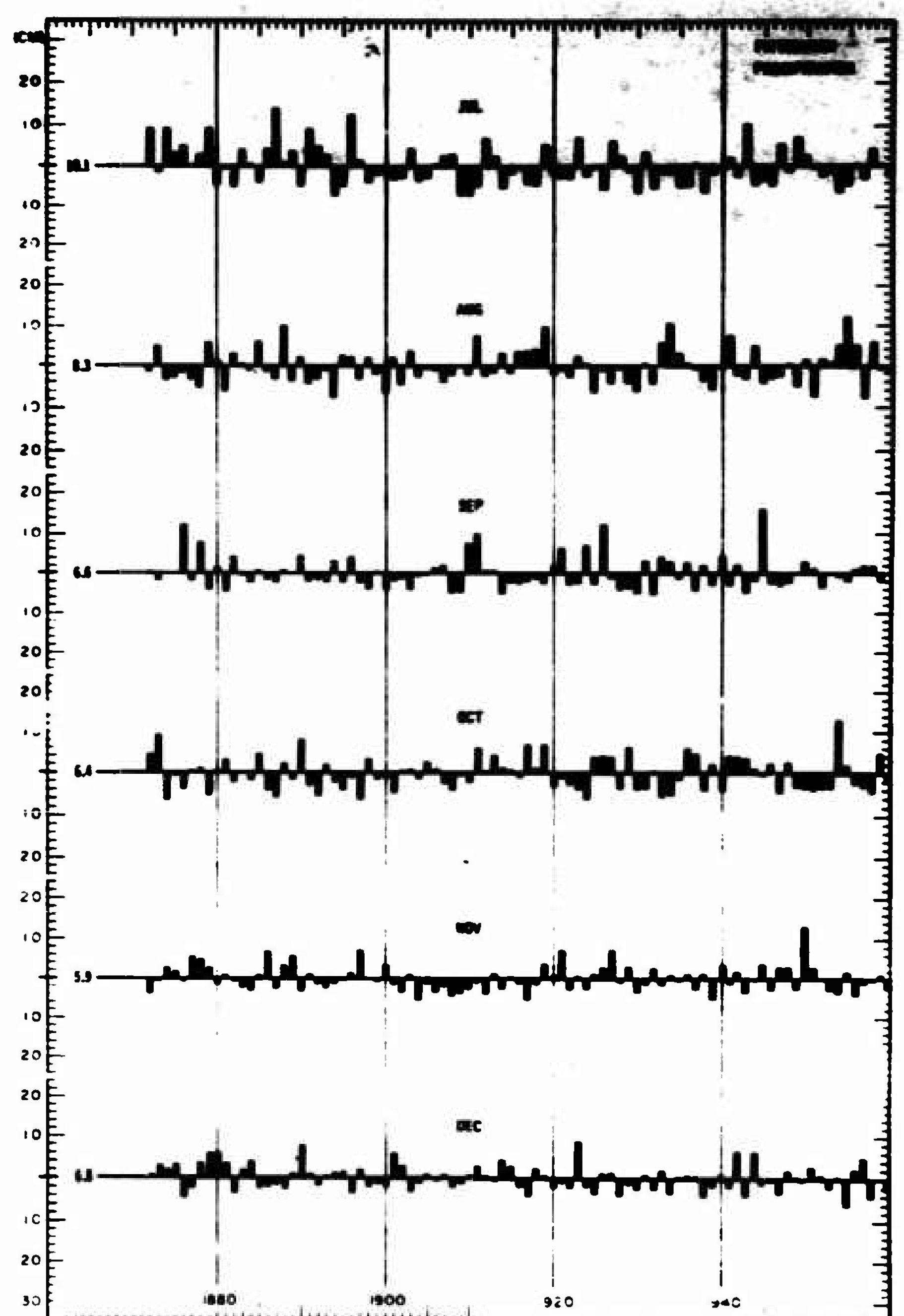


FIGURE 23B

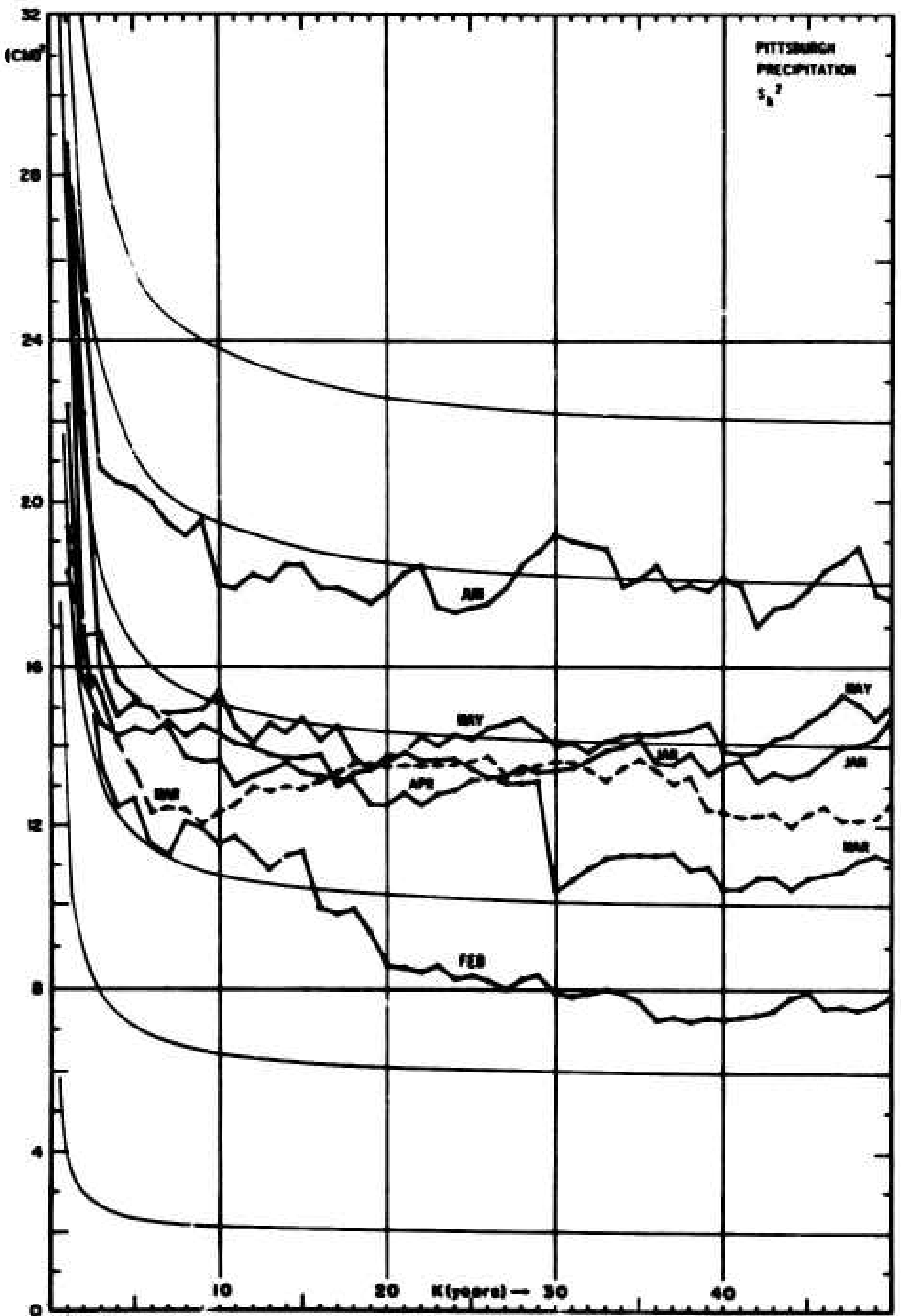


FIGURE 23C

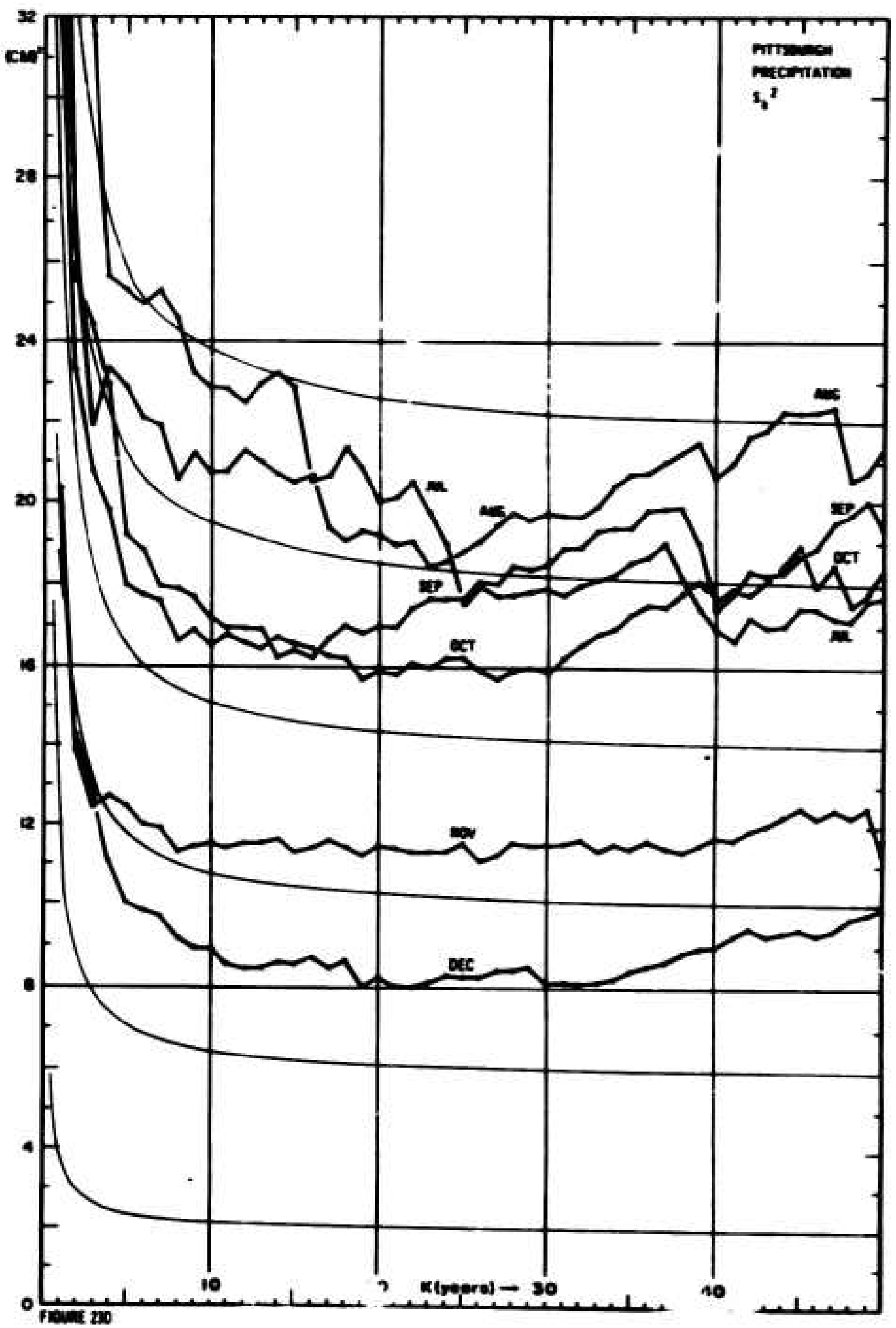
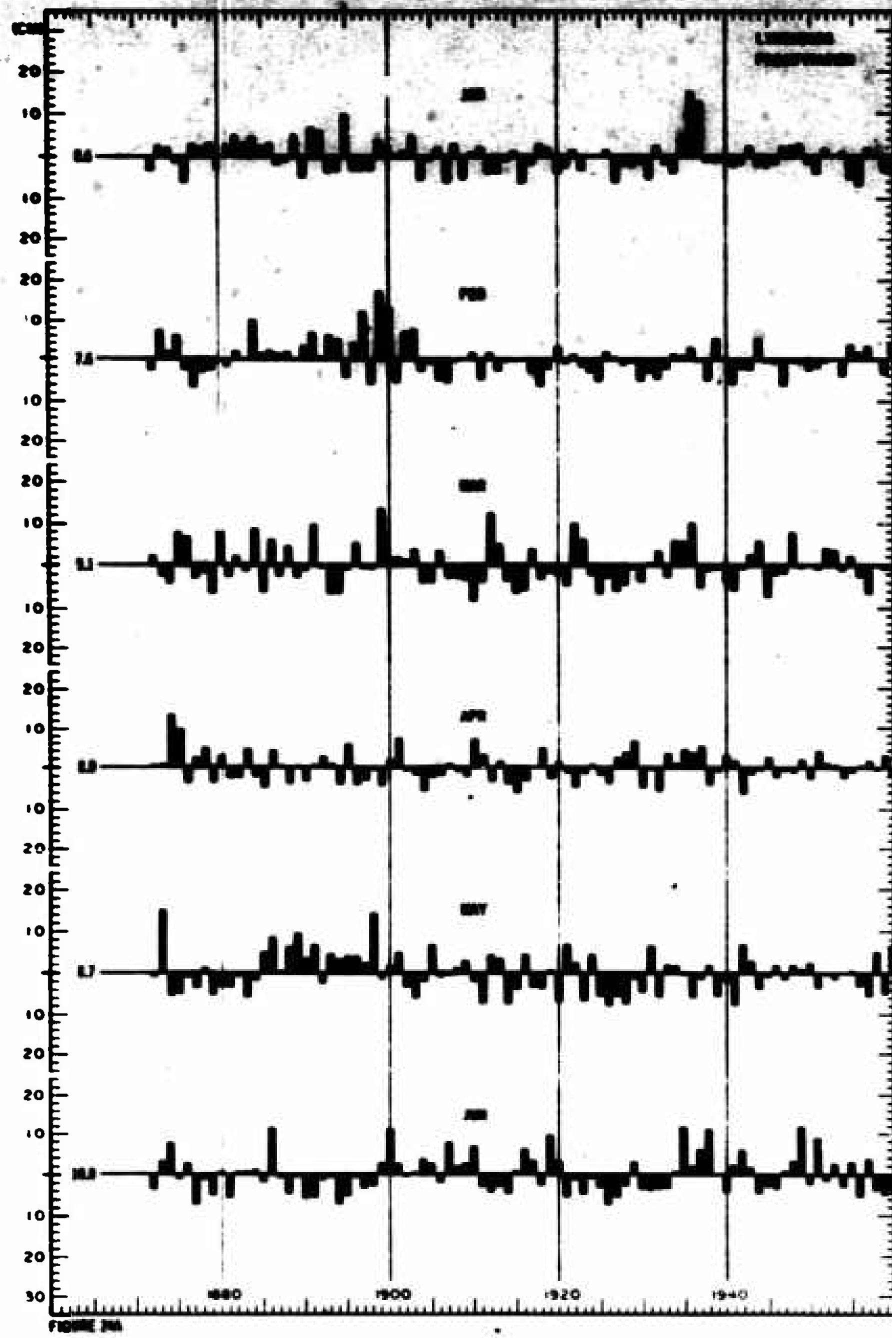
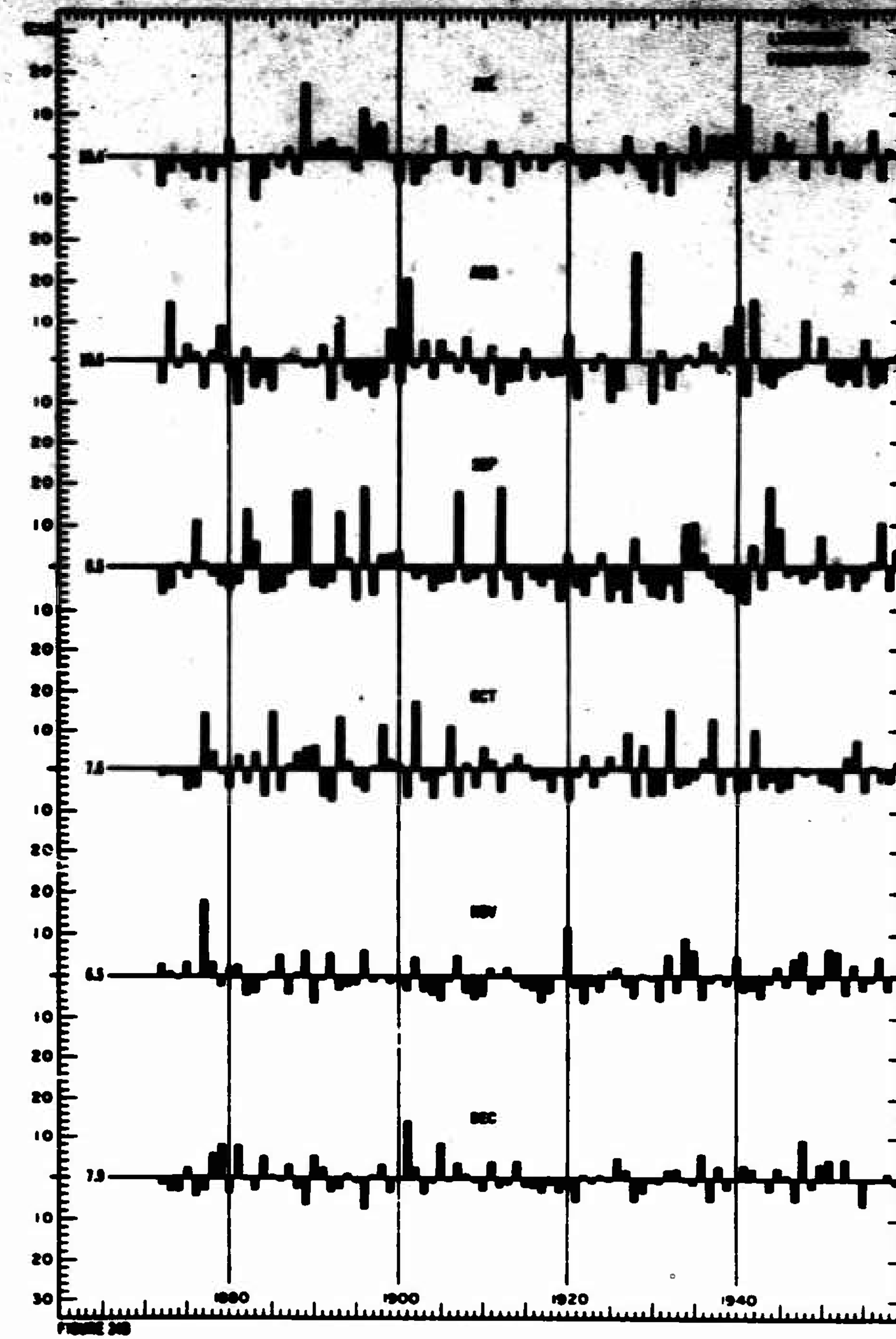


FIGURE 23D



APR
1880
1900
1920
1940



SEP
OCT
DEC
1880
1900
1920
1940

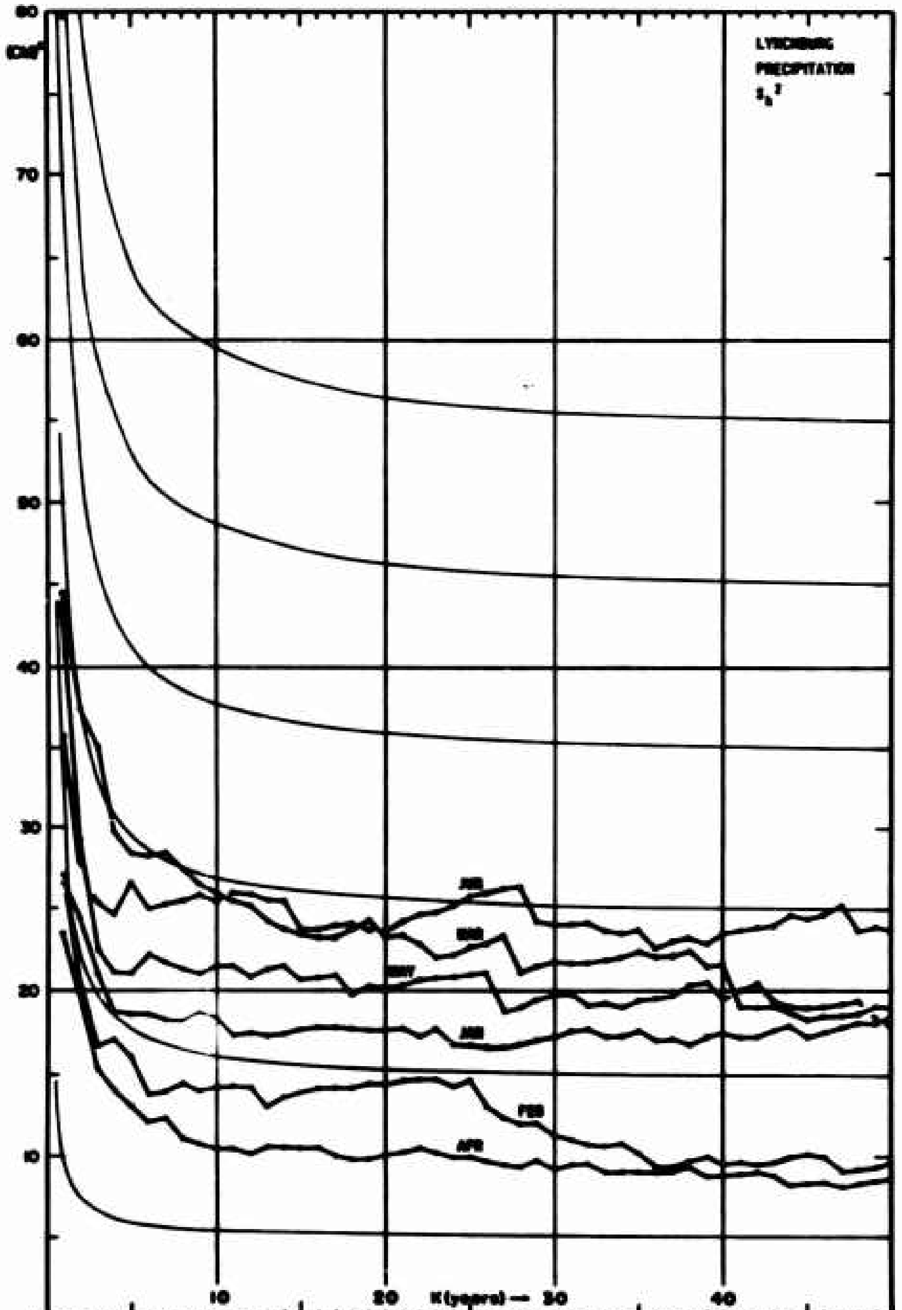


FIGURE 3C

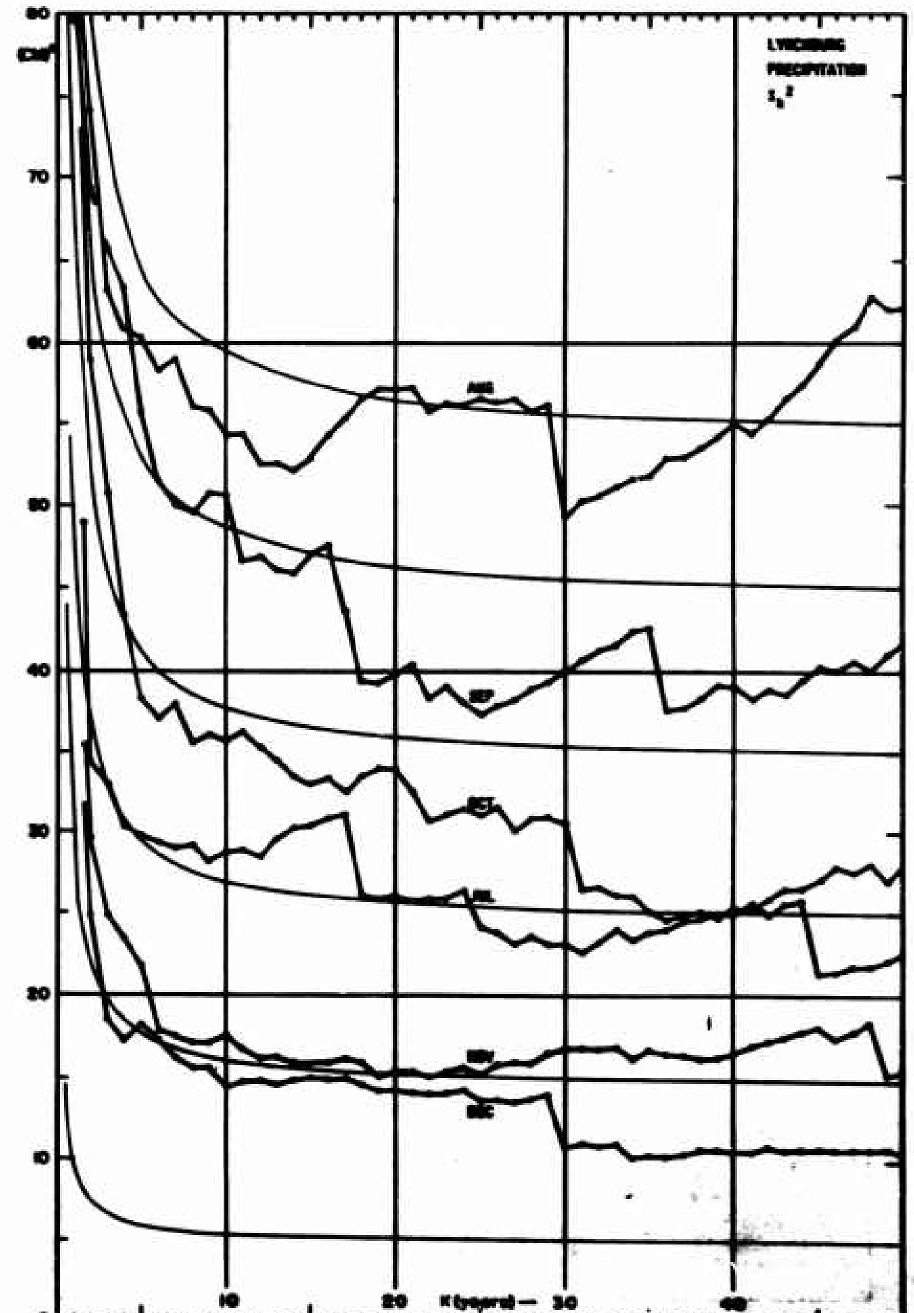


FIGURE 3D

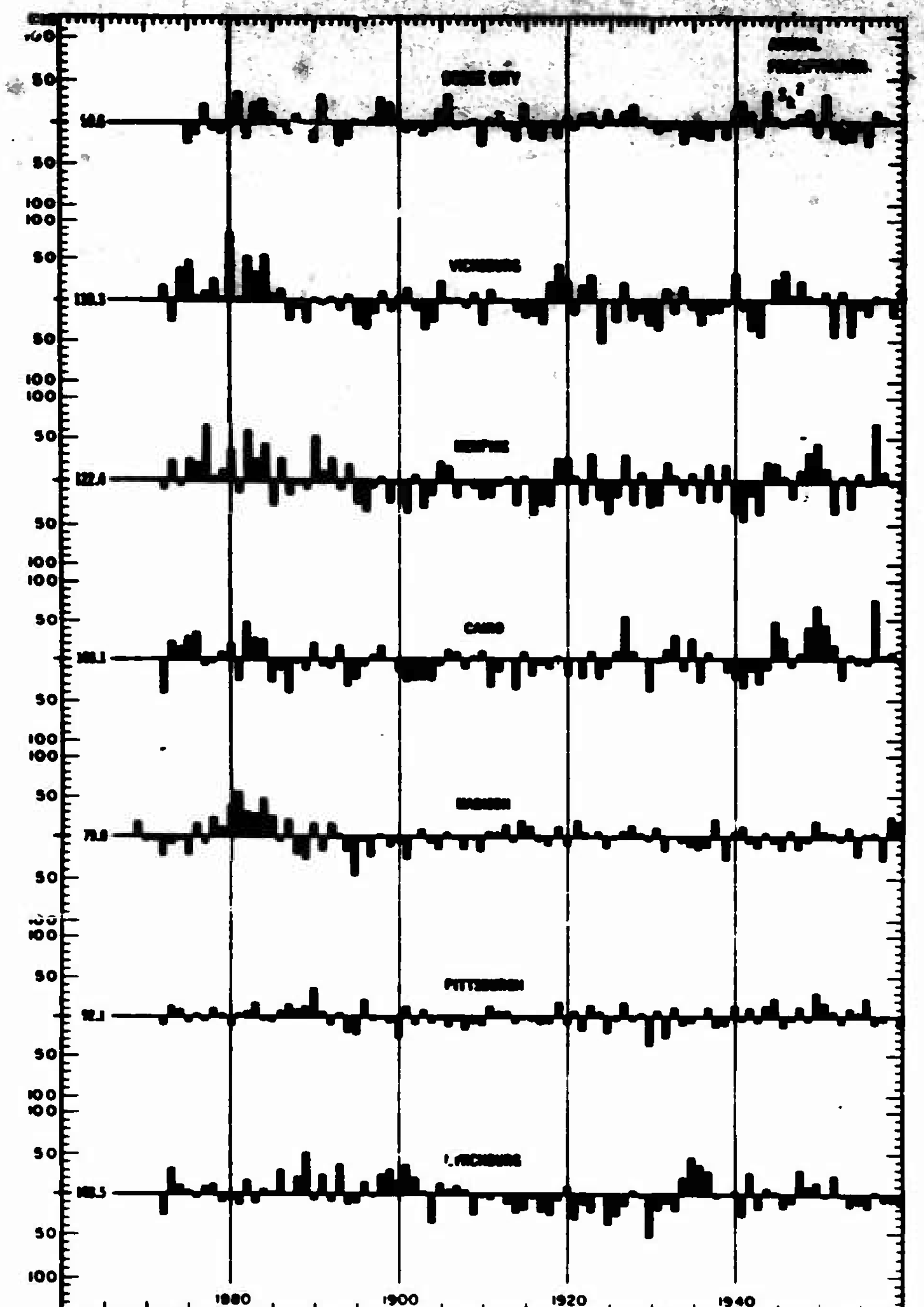


FIGURE 25A

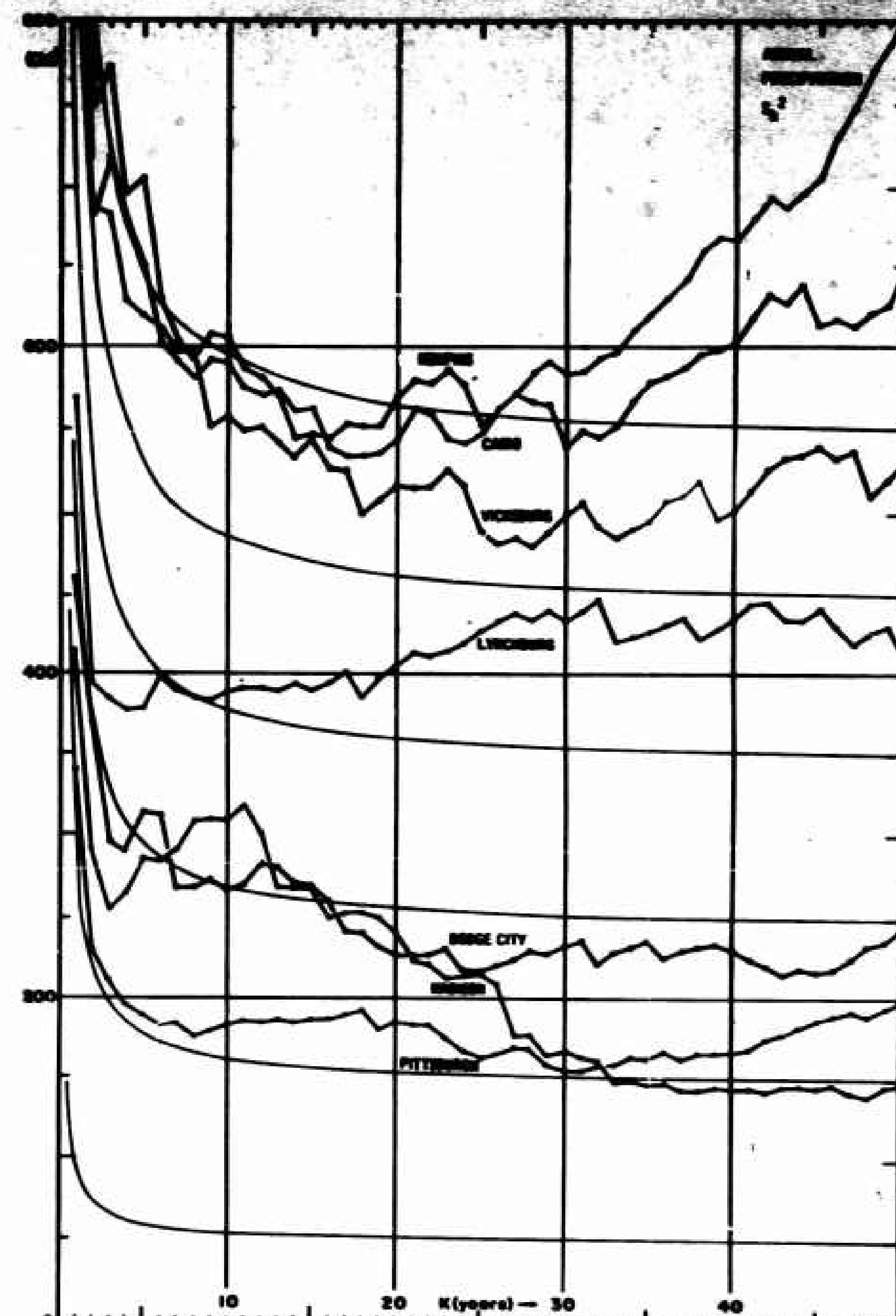


FIGURE 25B

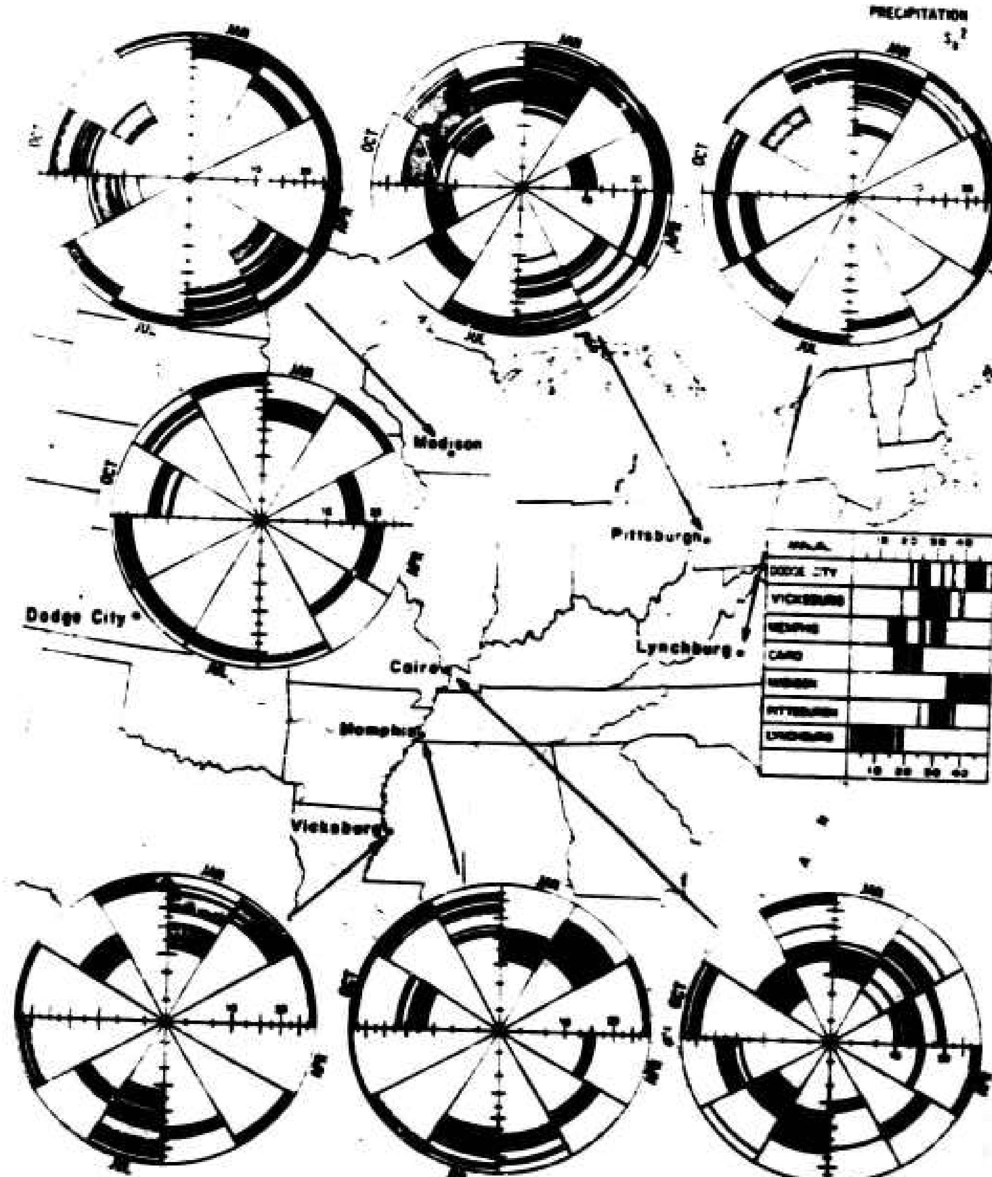

PRECIPITATION
Madison
Pittsburgh
Dodge City
Lynchburg
Cairo
Memphis
Vicksburg
DODGE CITY
VICKSBURG
MEMPHIS
CAIRO
MADISON
PITTSBURGH
LYNCHBURG
JAN
APR
JUL
OCT

FIGURE 26

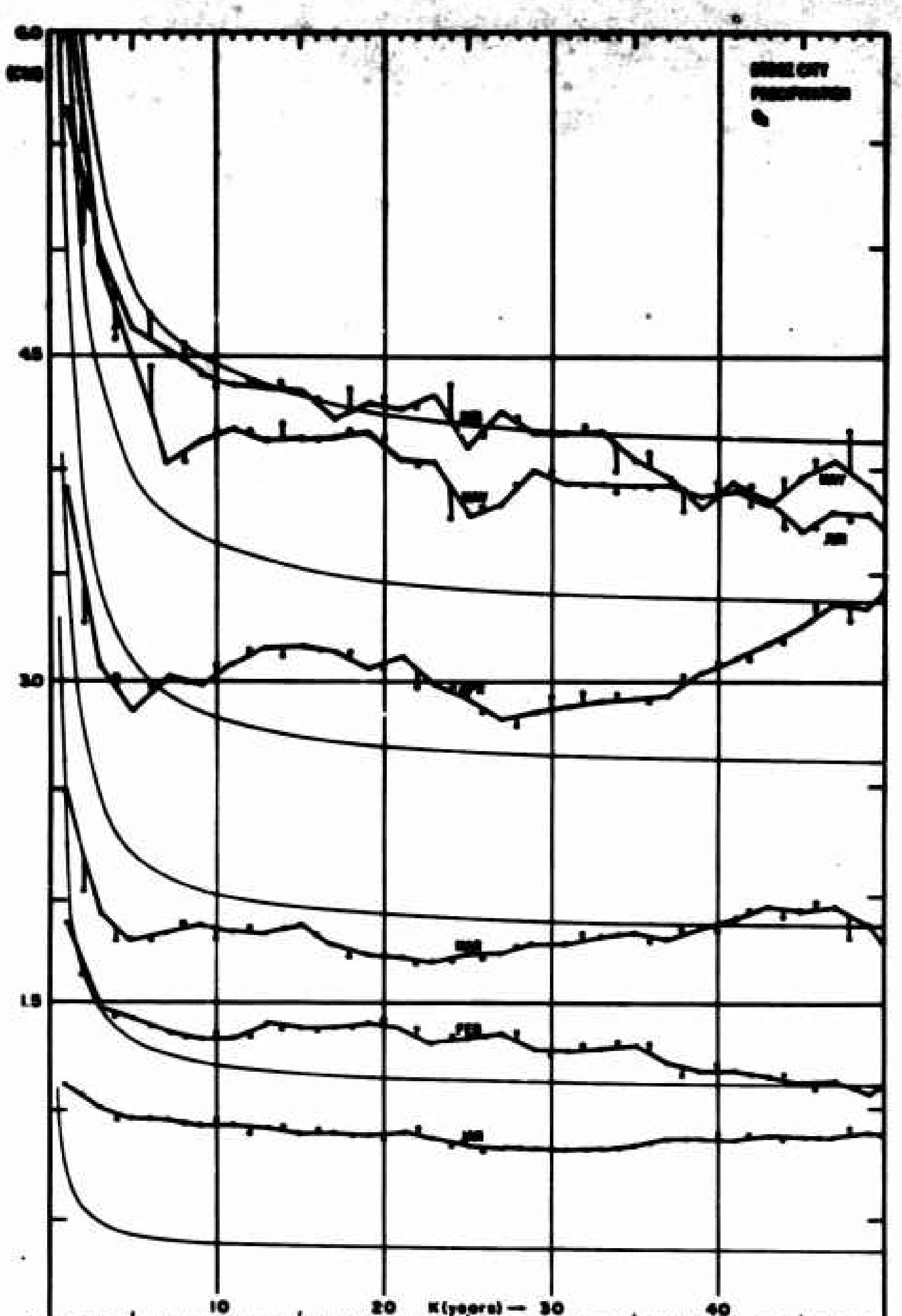


FIGURE 27A

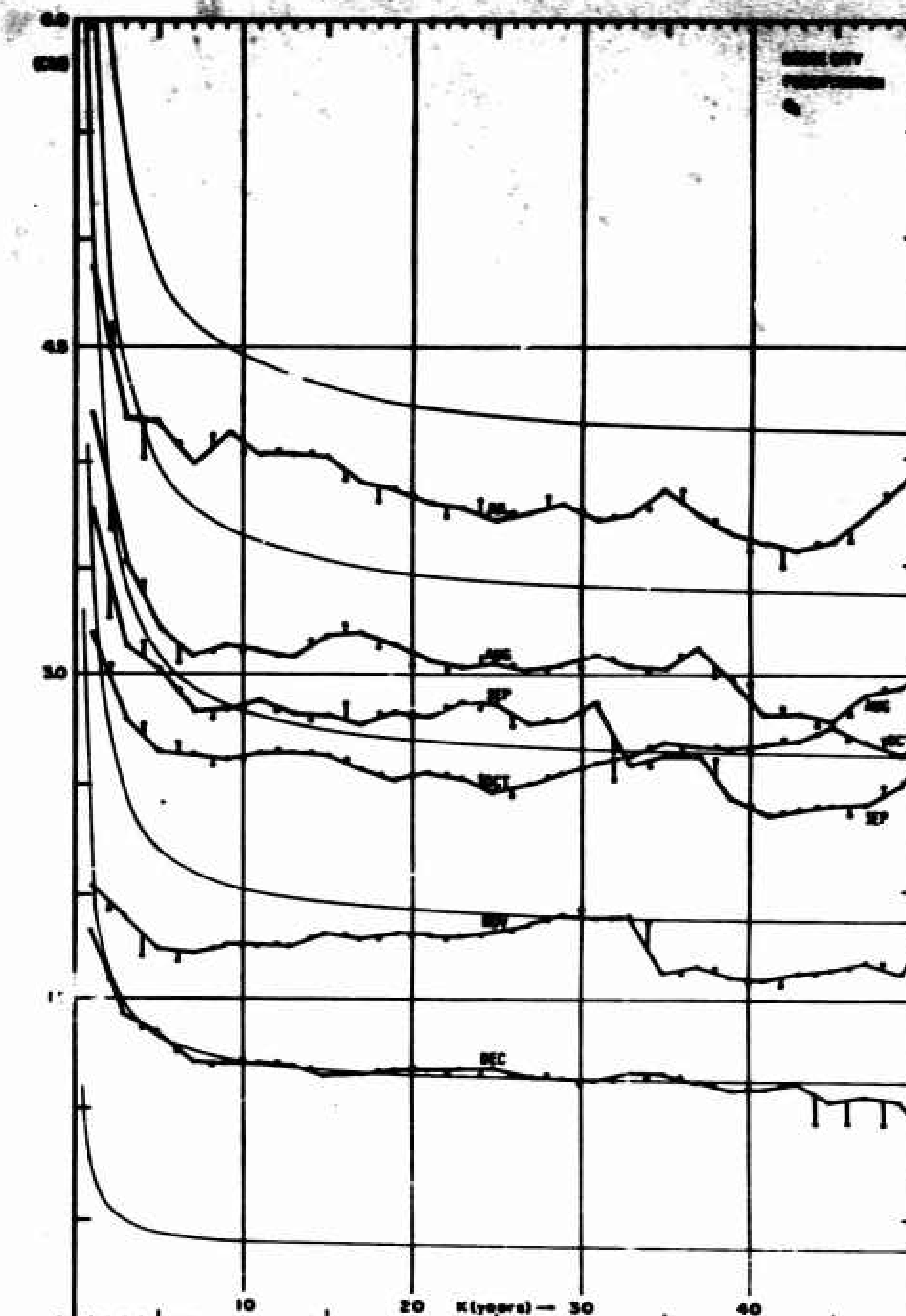
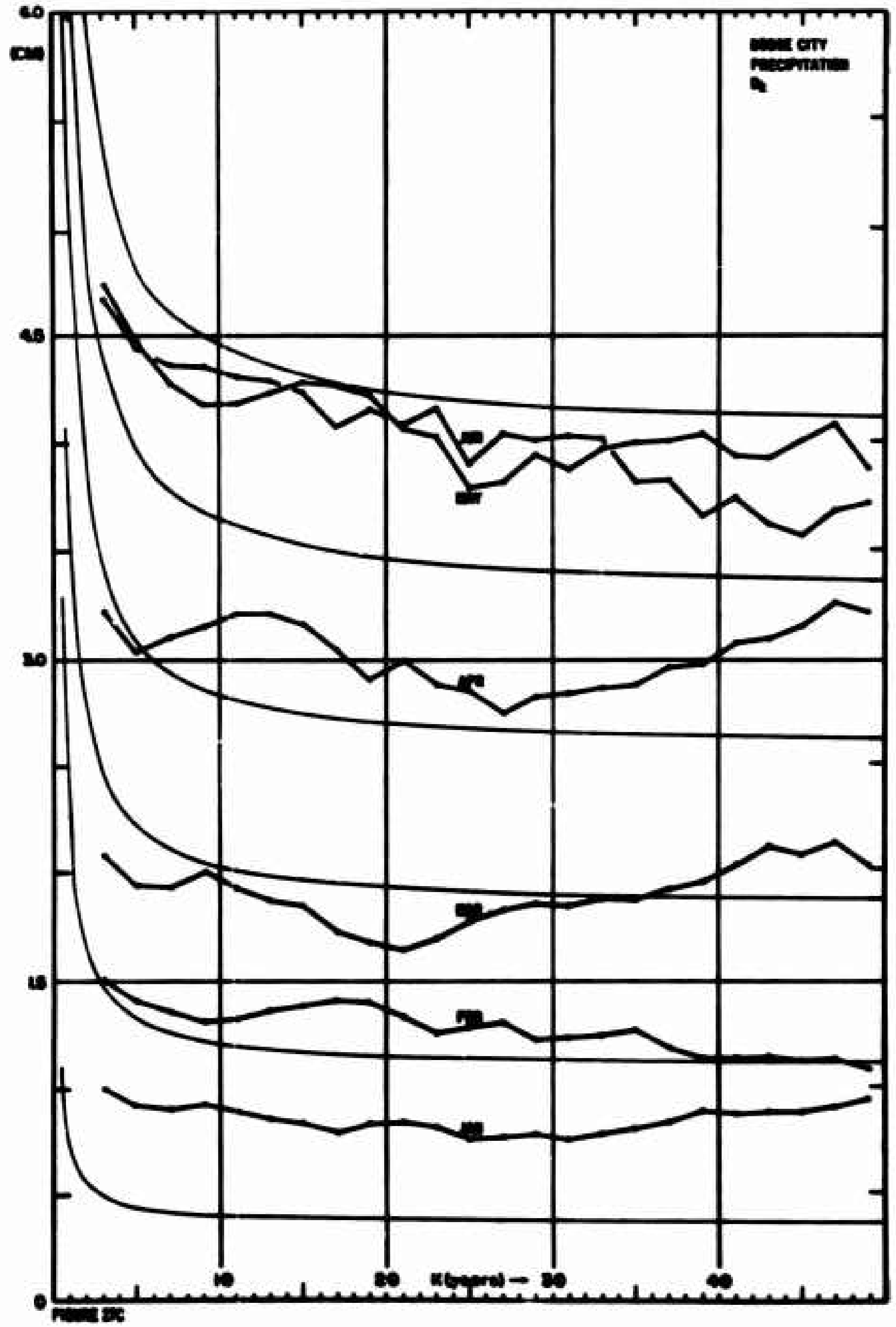
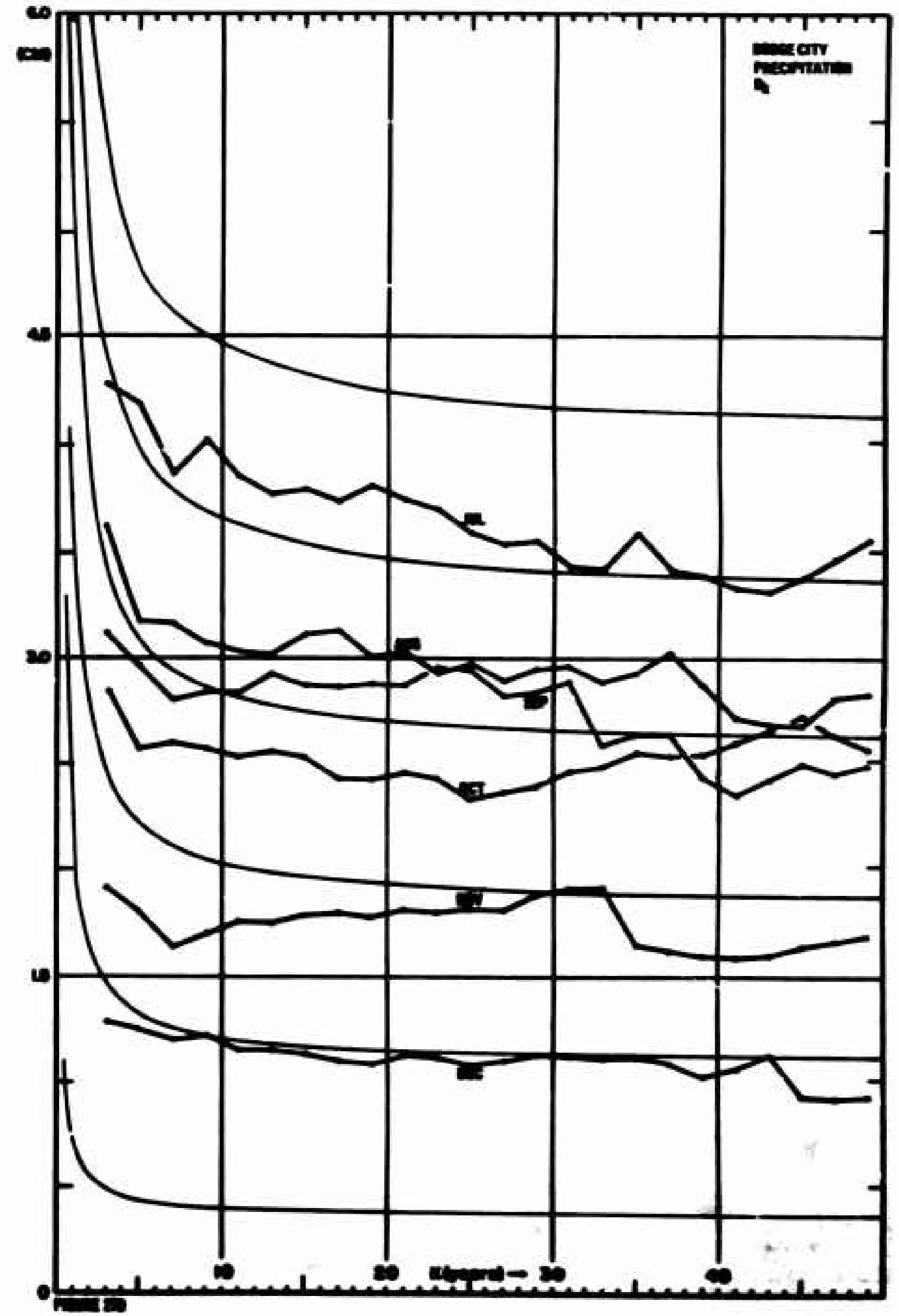


FIGURE 27B



DODGE CITY
PRECIPITATION
6.0
(CM)
4.5
3.0
1.5
0
10
20
30
40
K (years) →



DODGE CITY
PRECIPITATION
6.0
(CM)
4.5
3.0
1.5
0
10
20
30
40
K (years) →

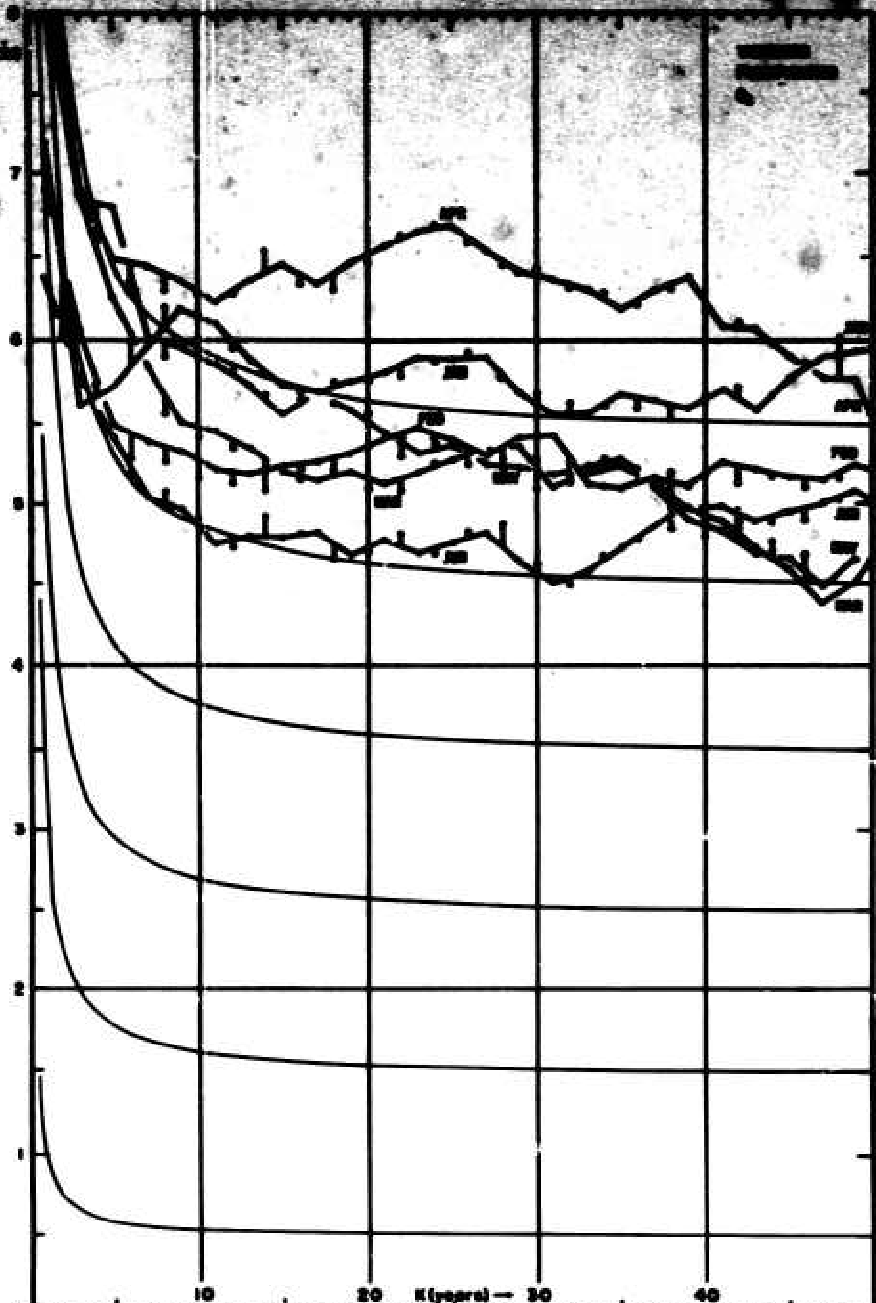


FIGURE [illegible]

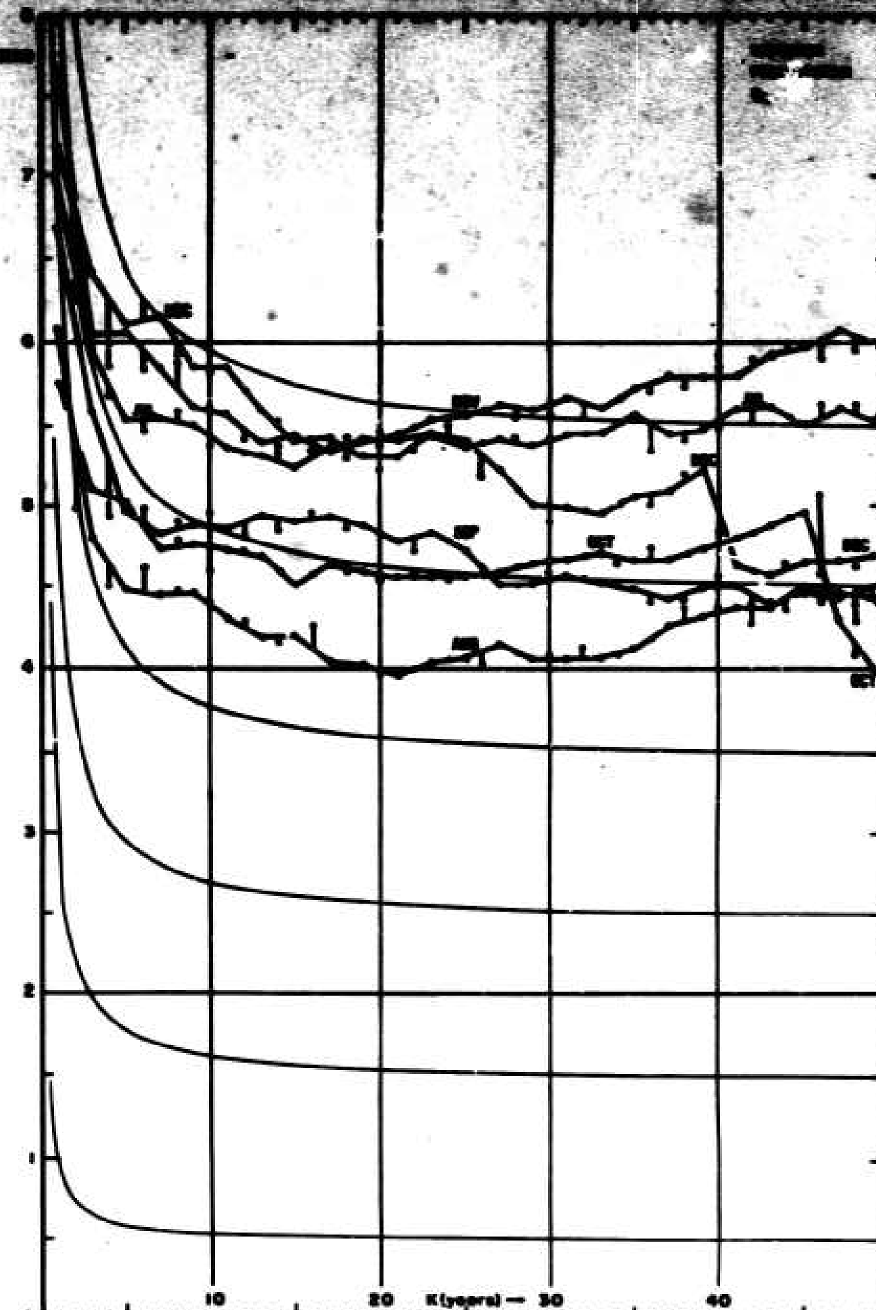


FIGURE [illegible]

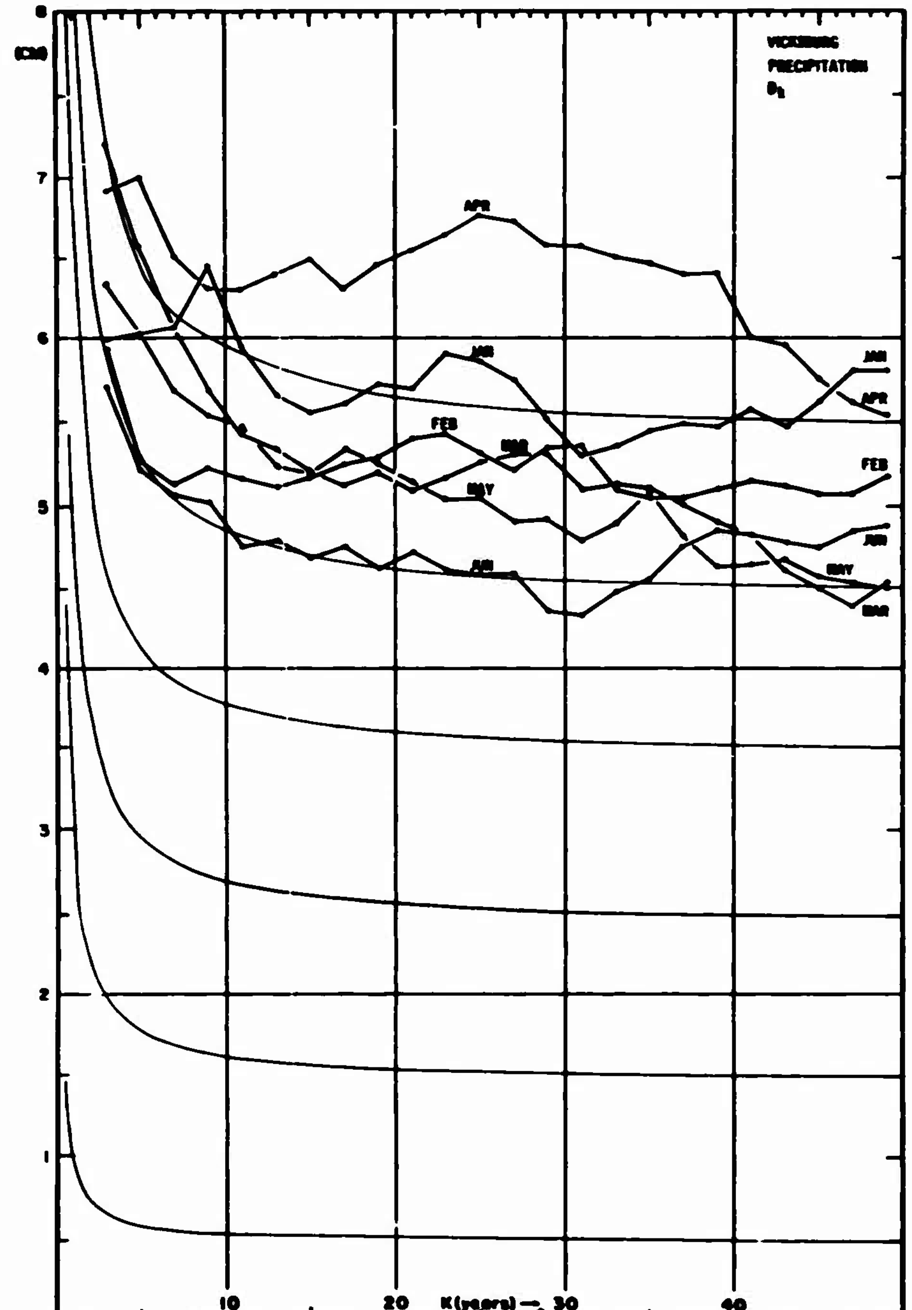


FIGURE [illegible]C

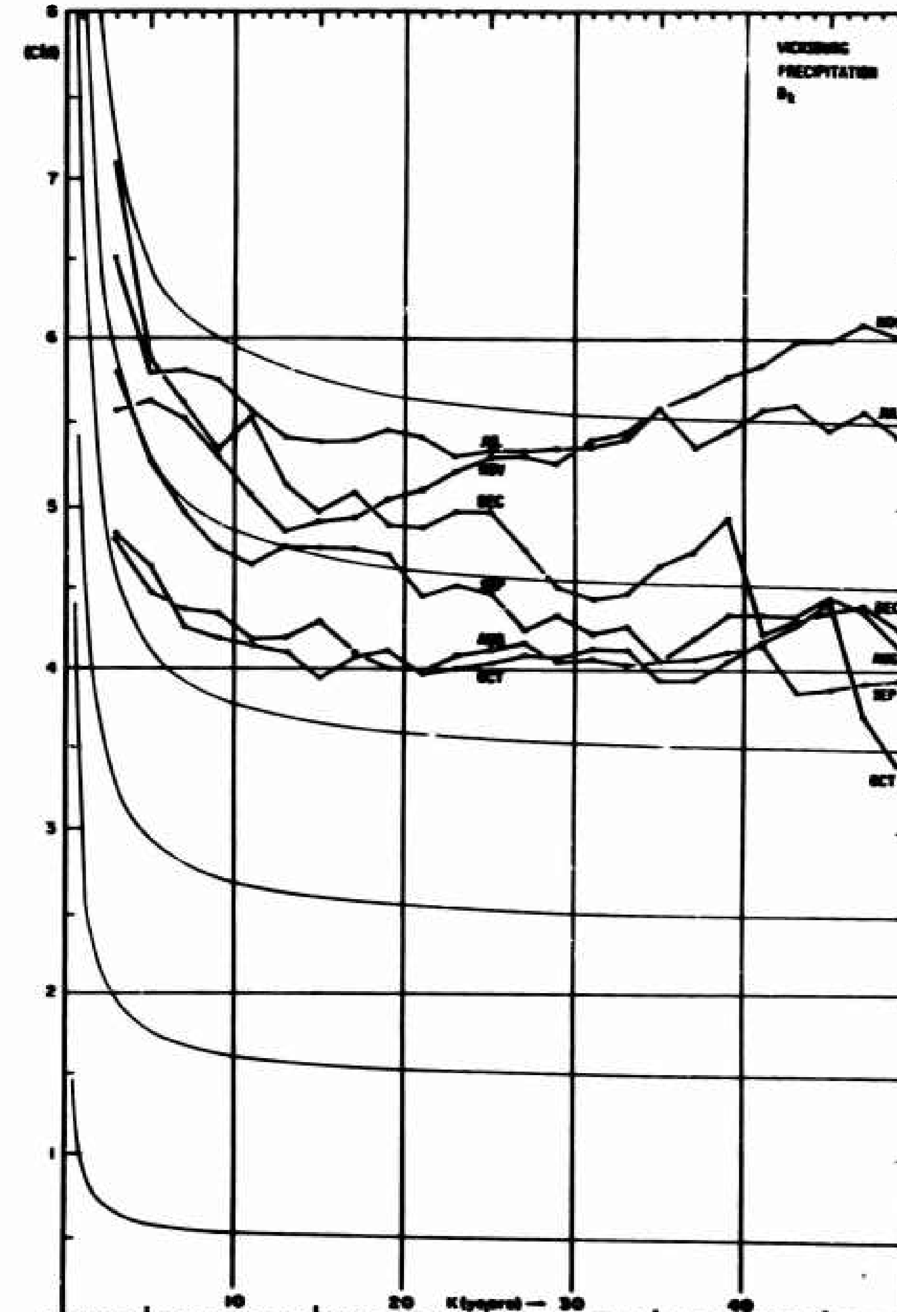


FIGURE [illegible]D

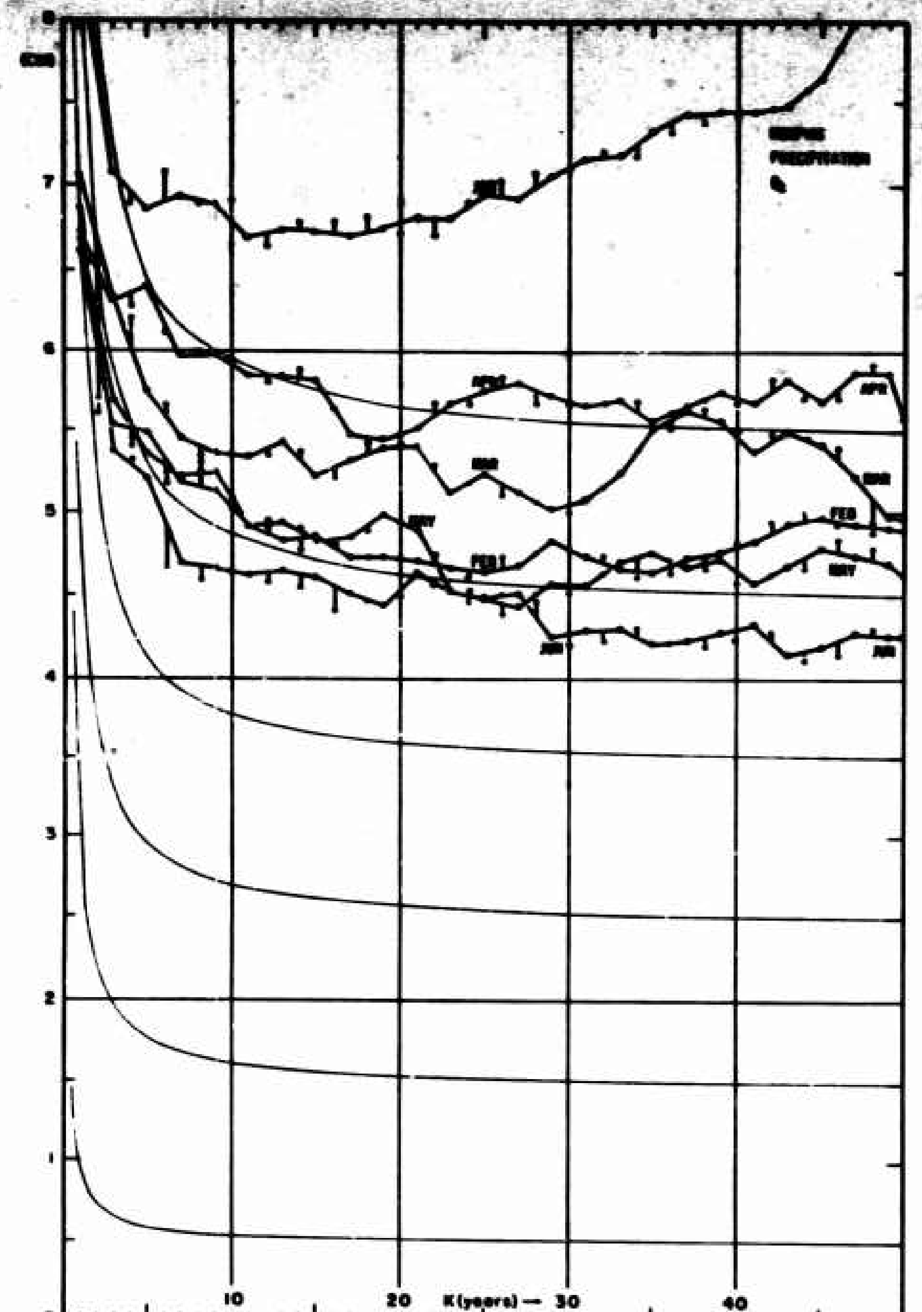


FIGURE 29A

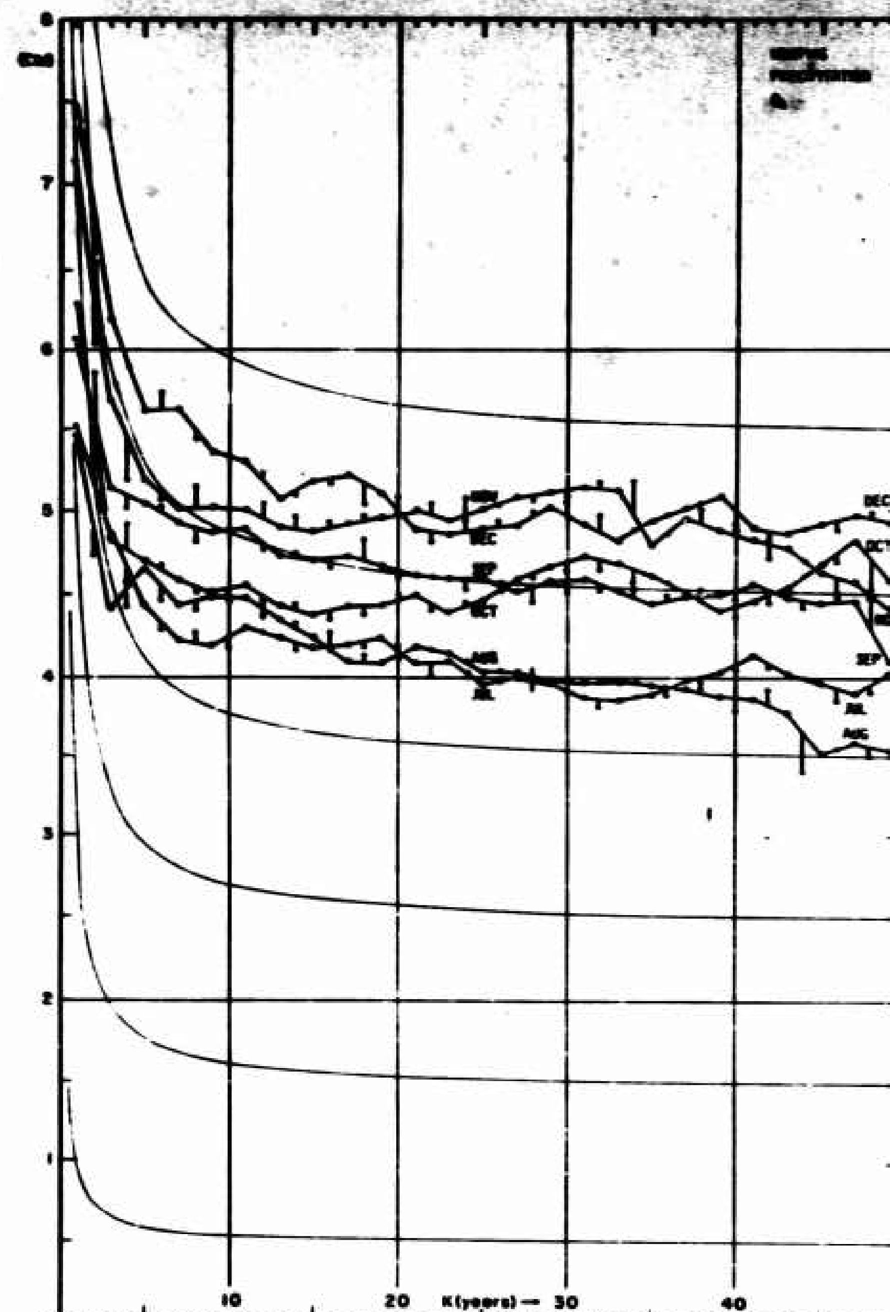


FIGURE 29B

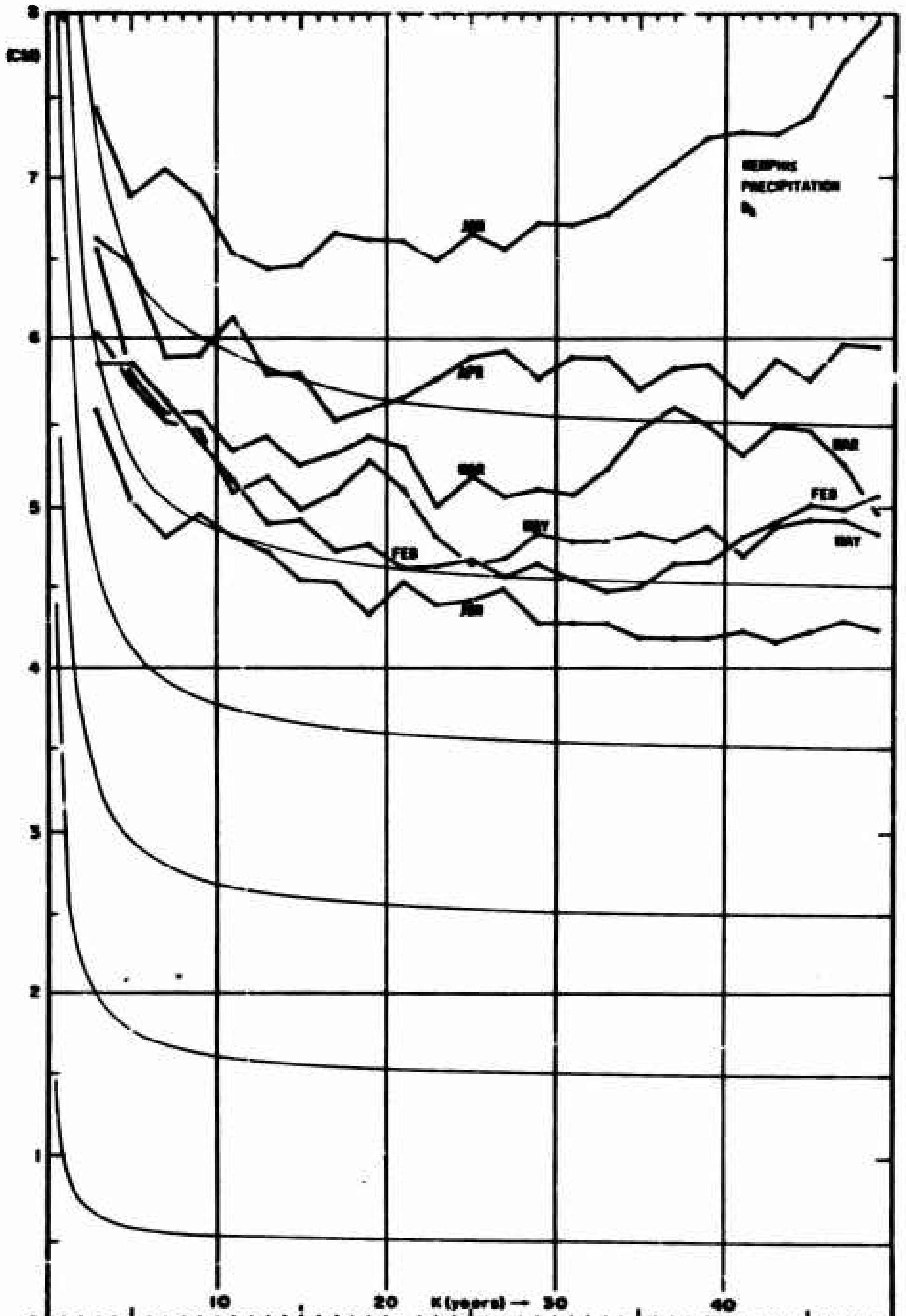


FIGURE 20C

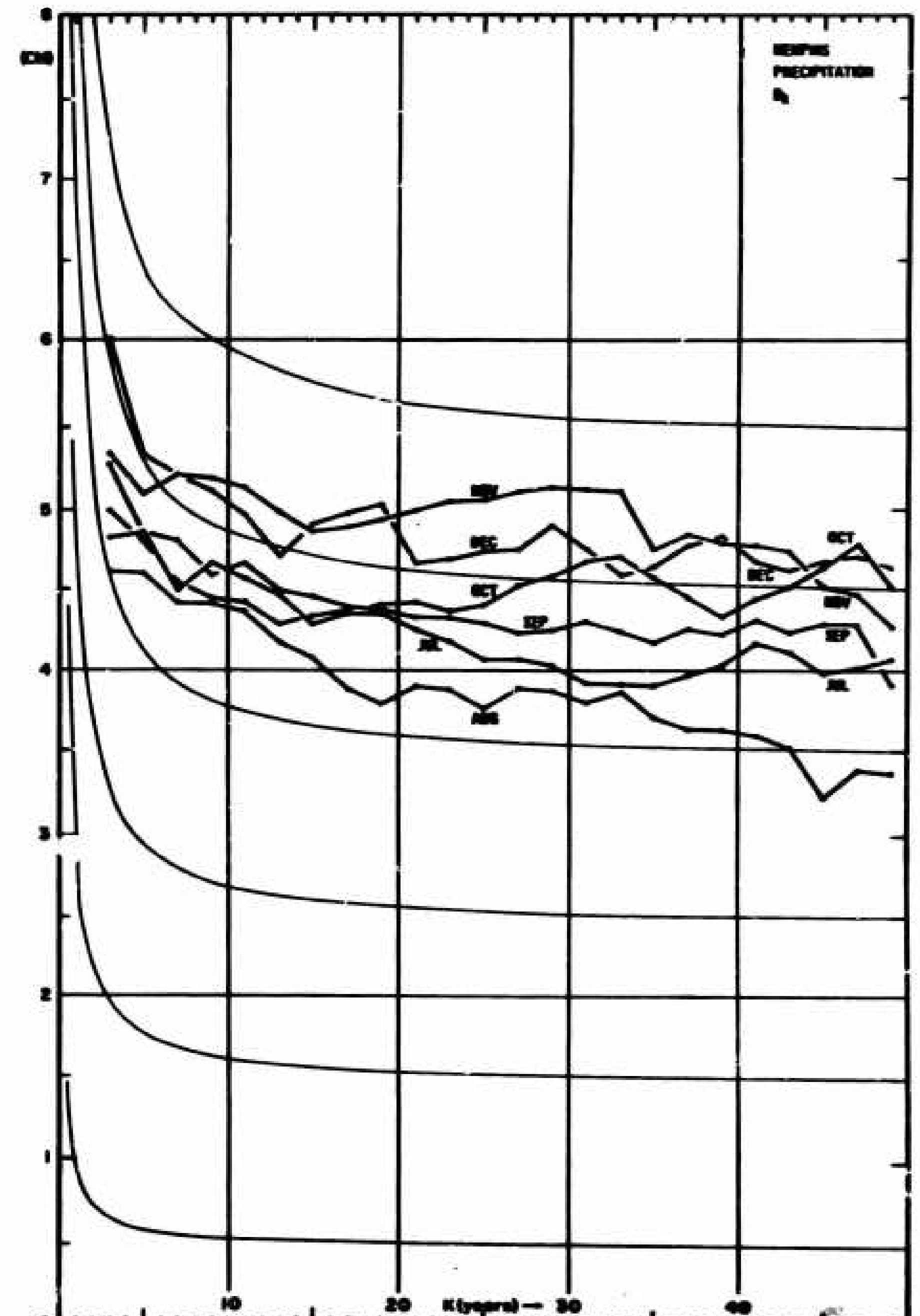


FIGURE 20D

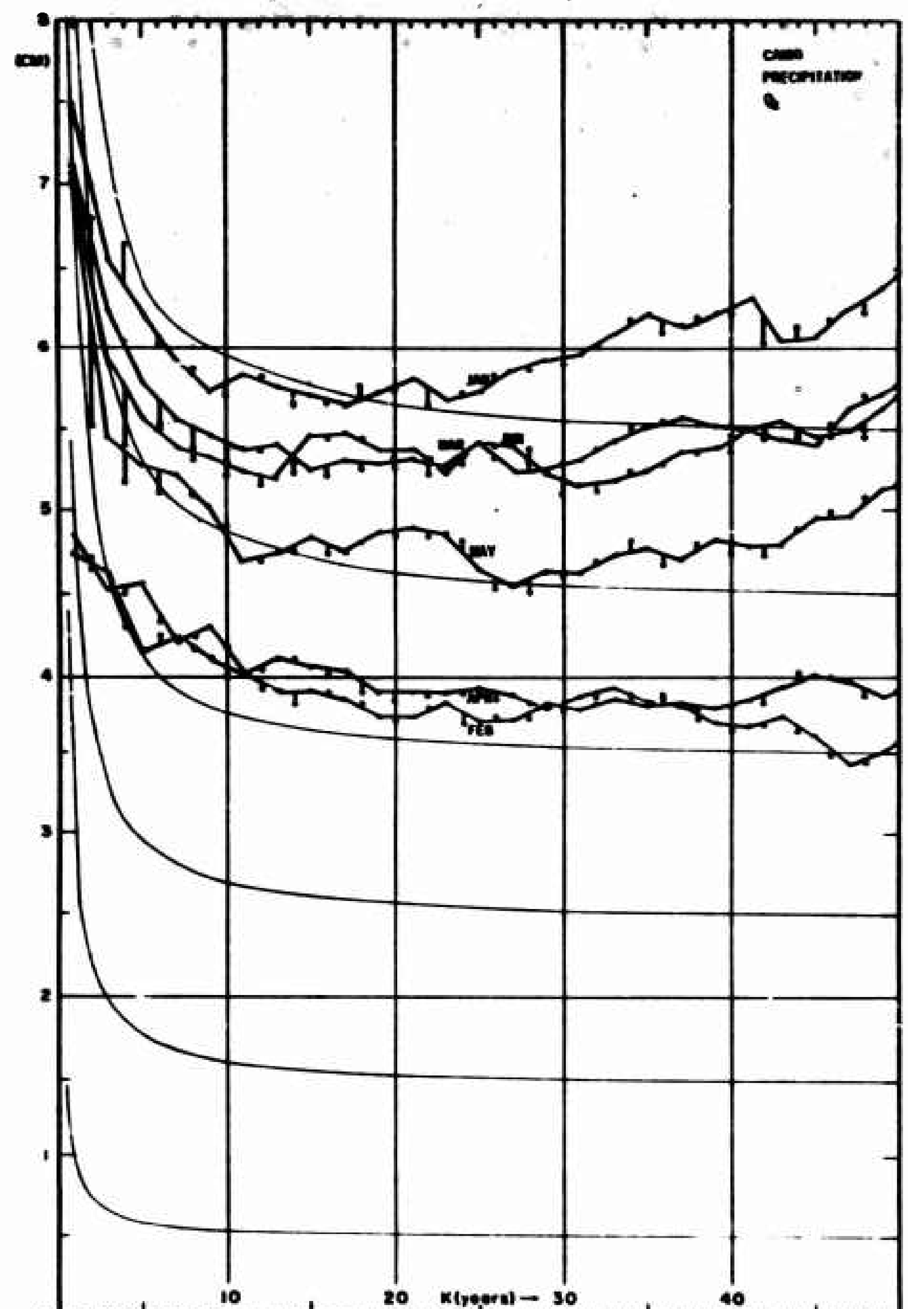


FIGURE [illegible]

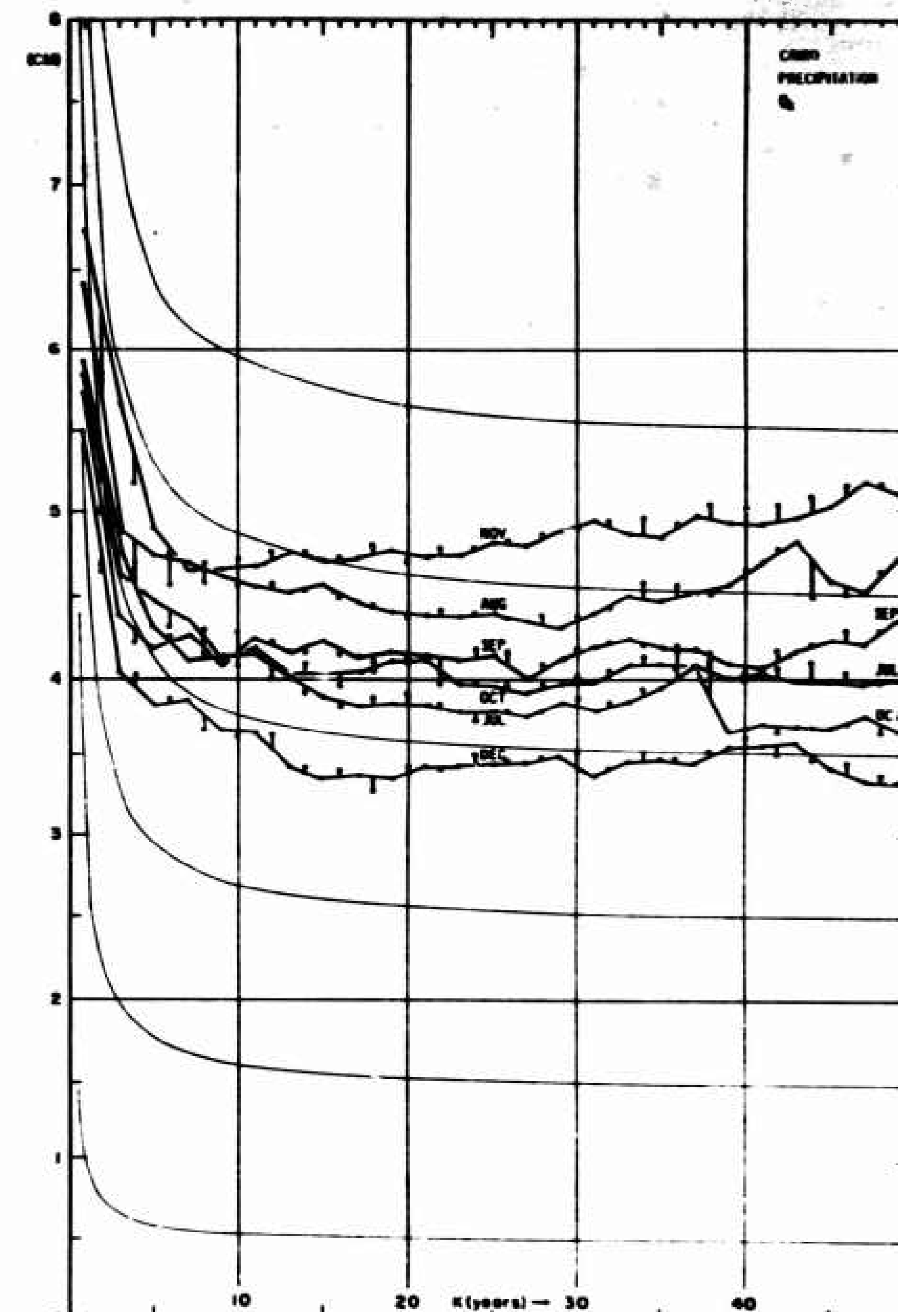
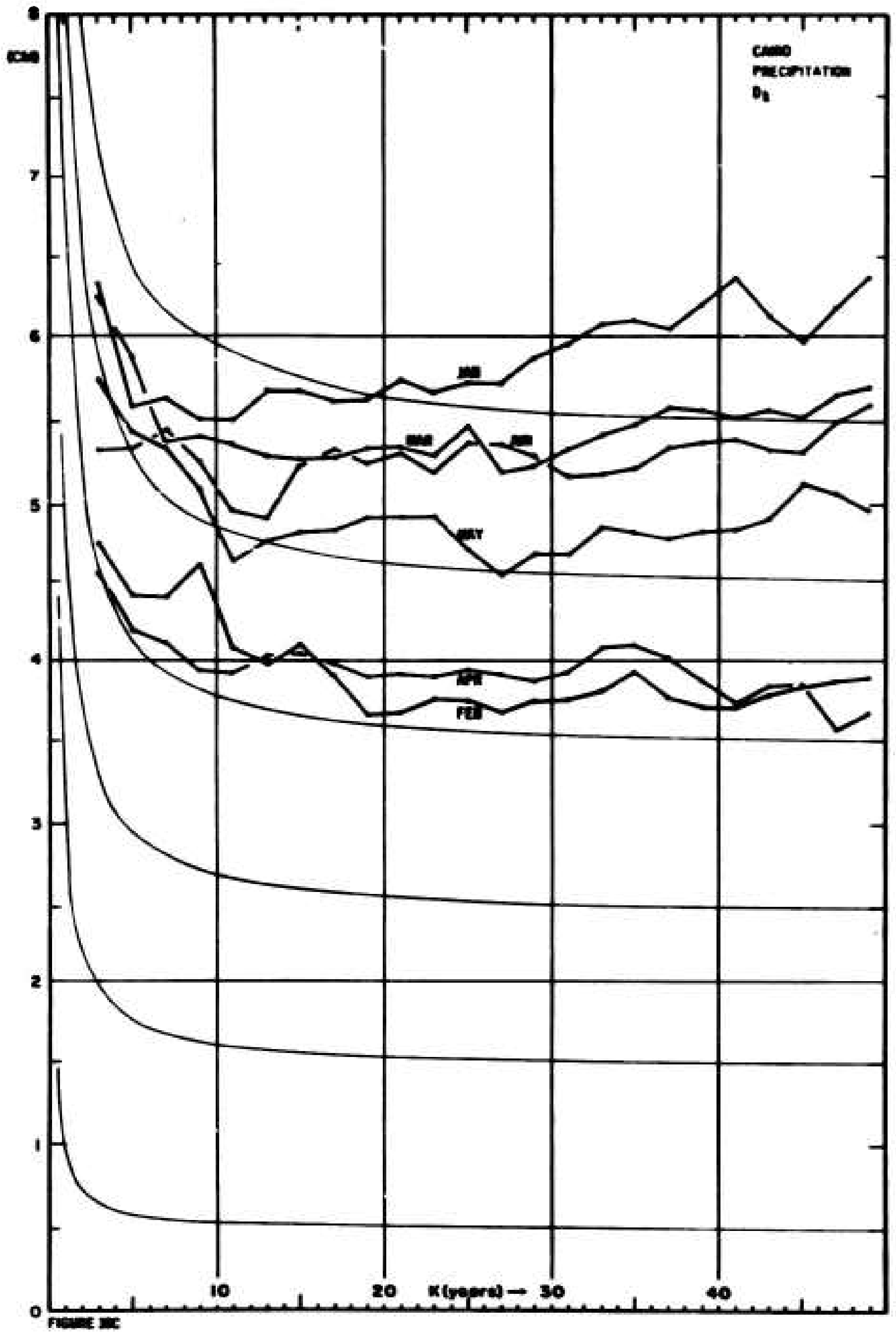
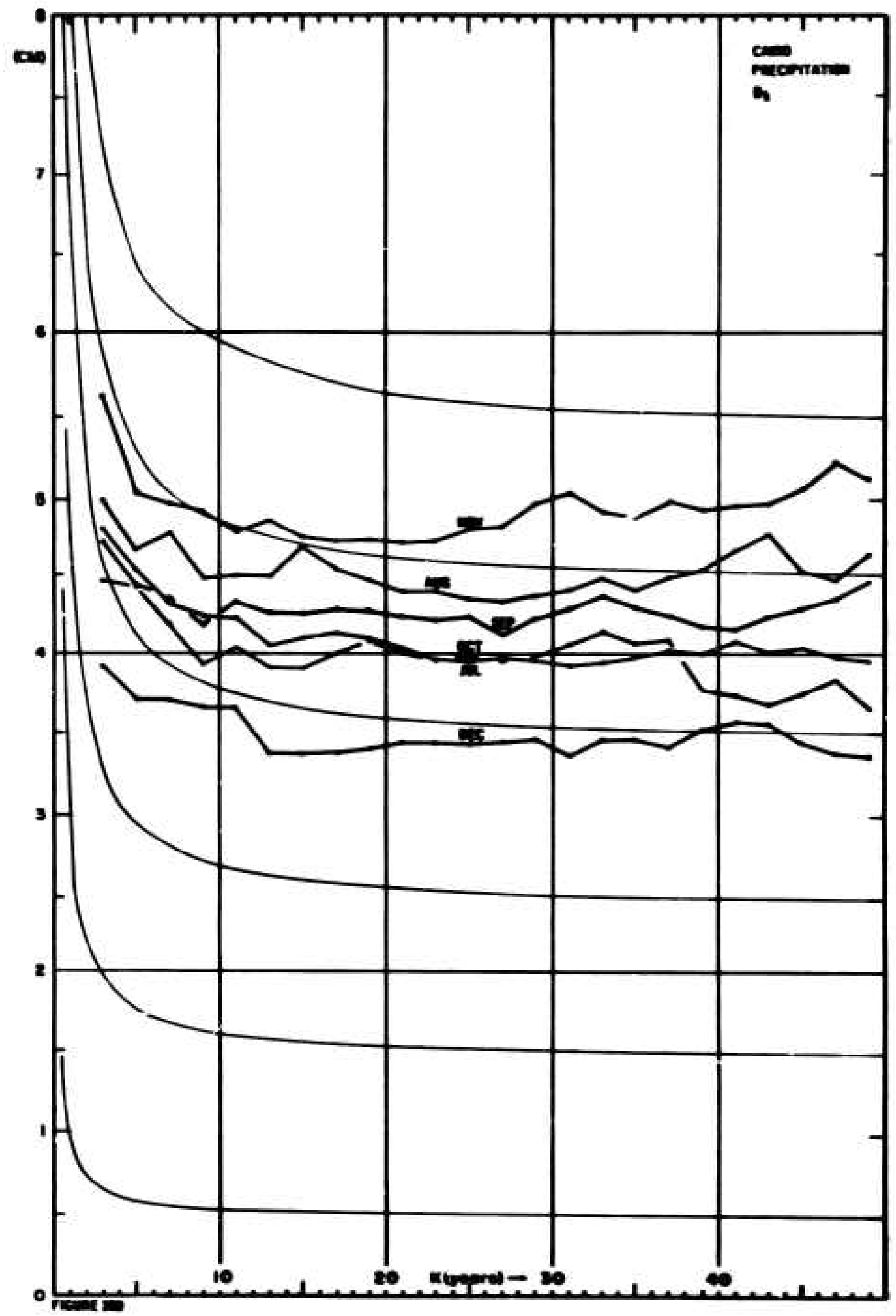


FIGURE [illegible]


CAIRO
PRECIPITATION
(CM)
JAN
MAR
JUN
MAY
APR
FEB
K(years) →
10
20
30
40


CAIRO
PRECIPITATION
(CM)
NOV
AUG
SEP
OCT
JUL
DEC
K(years) →
10
20
30
40

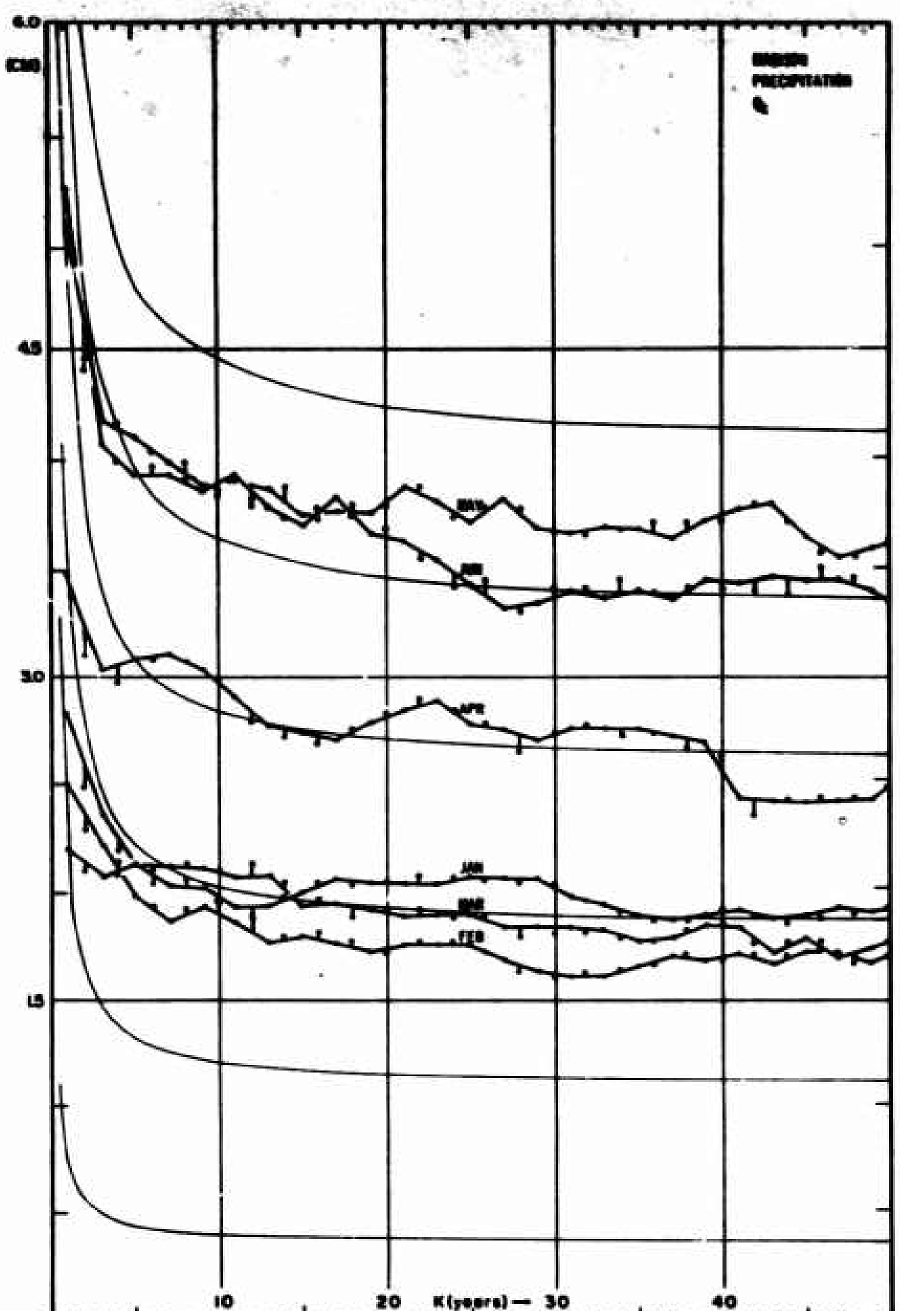


FIGURE 31A

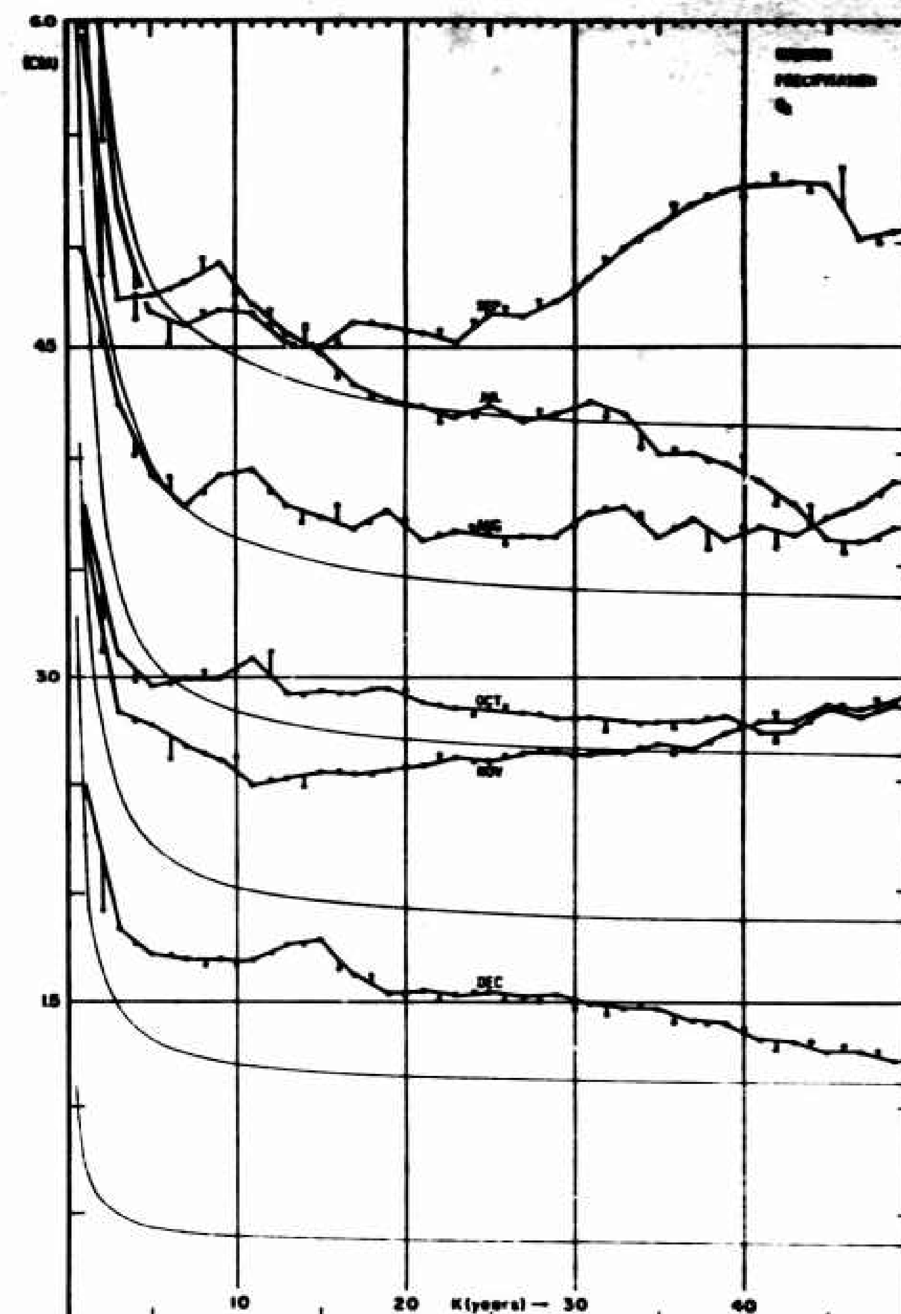


FIGURE 31B

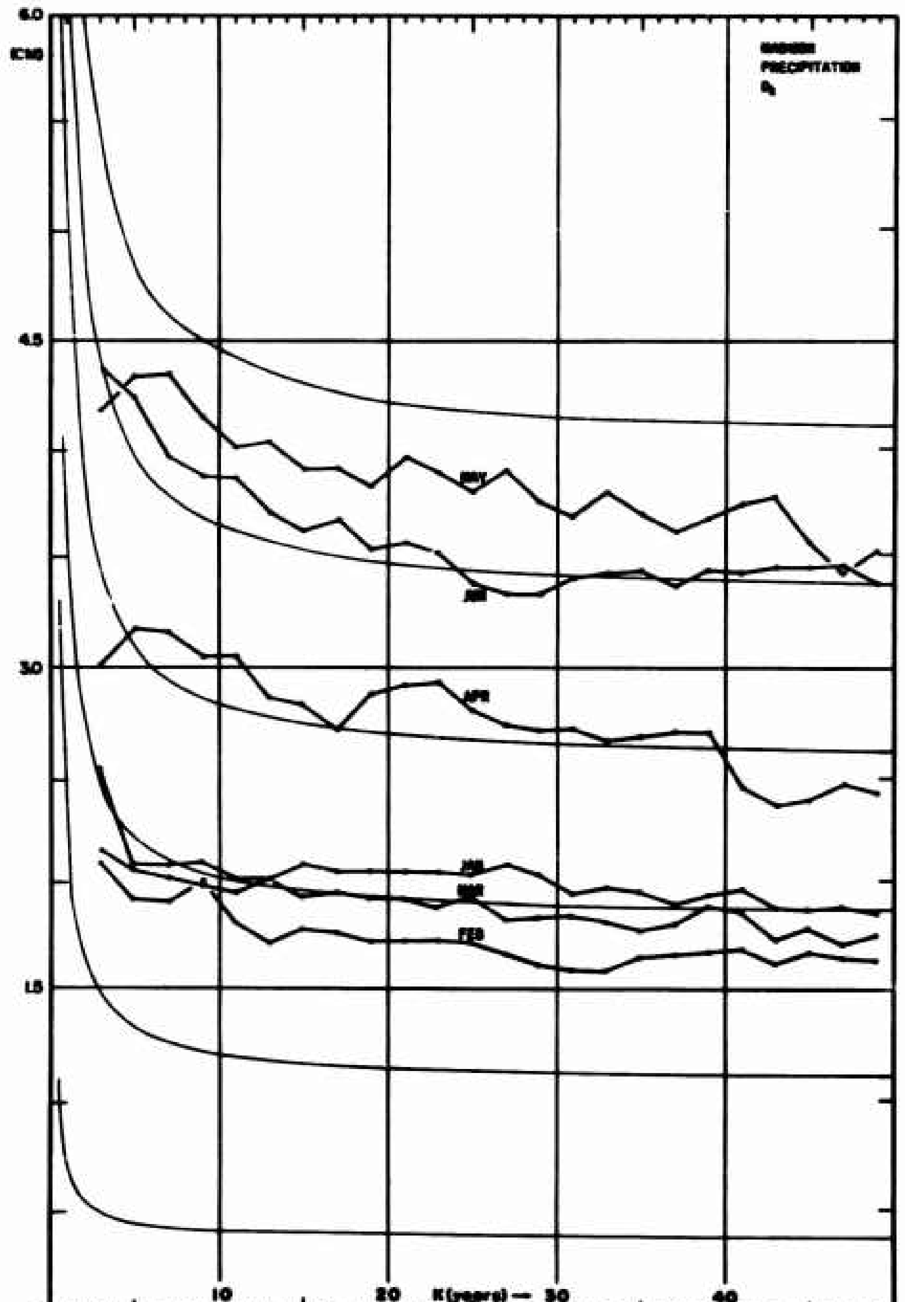


FIGURE 33C

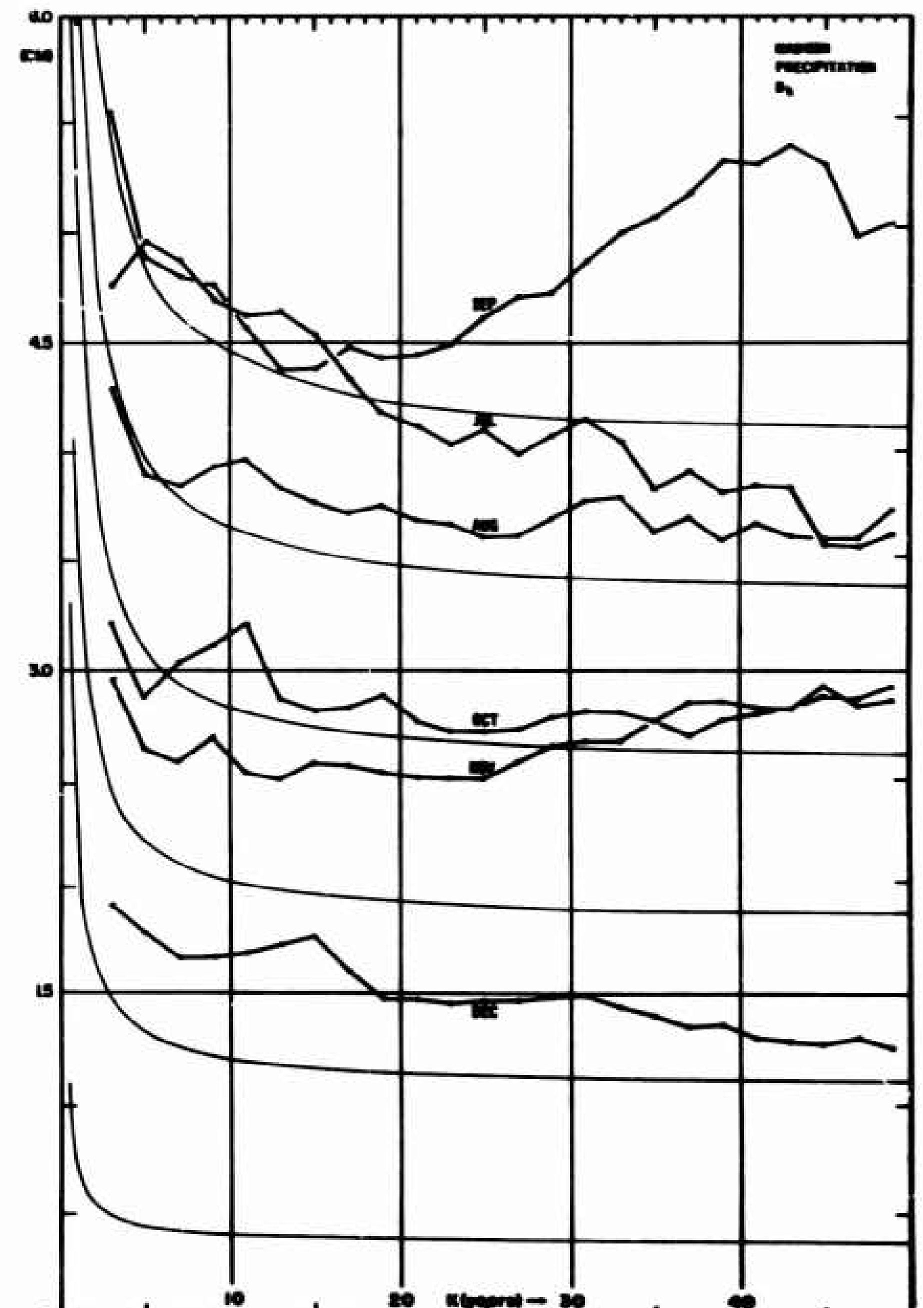


FIGURE 33D

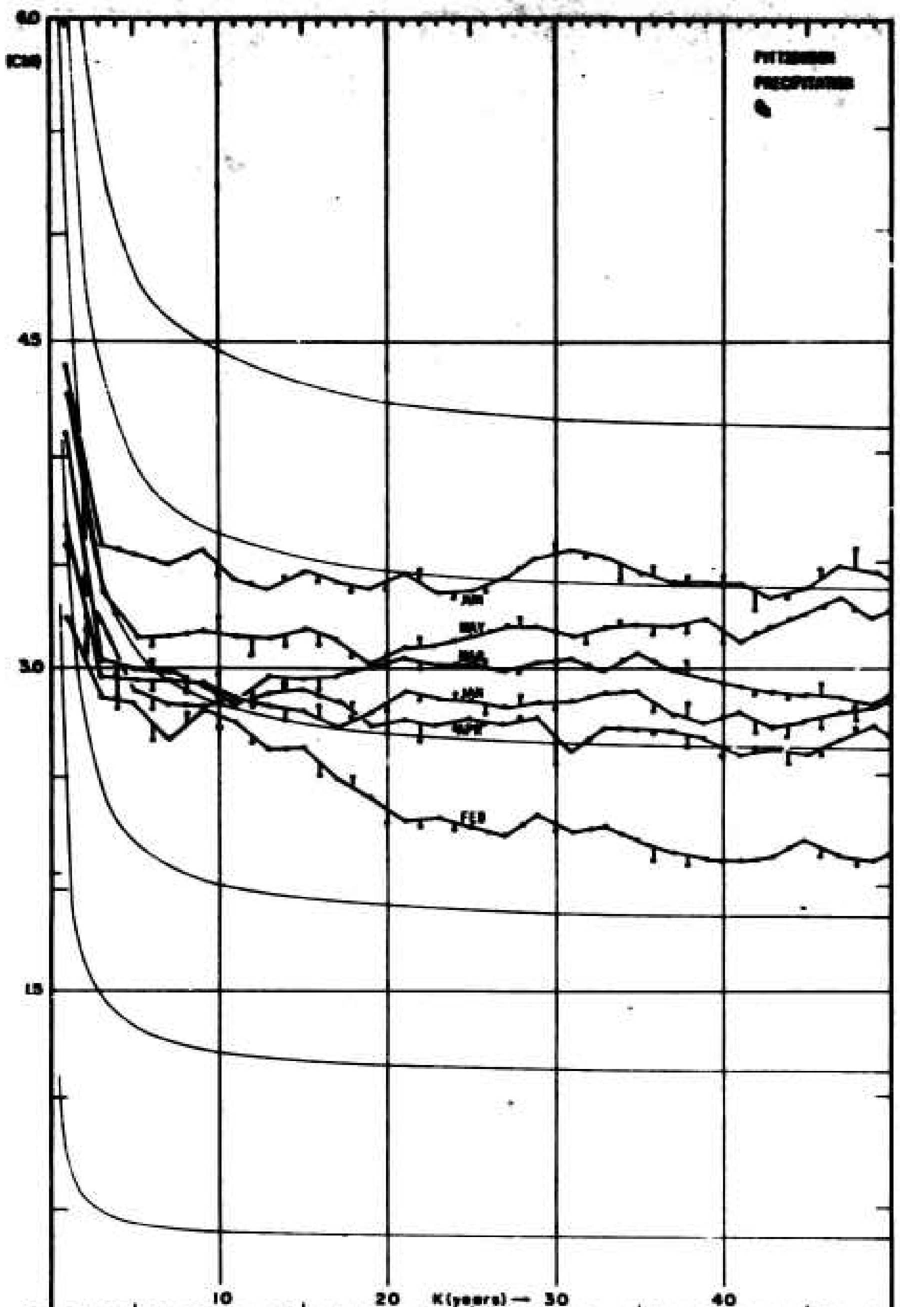


FIGURE 32A

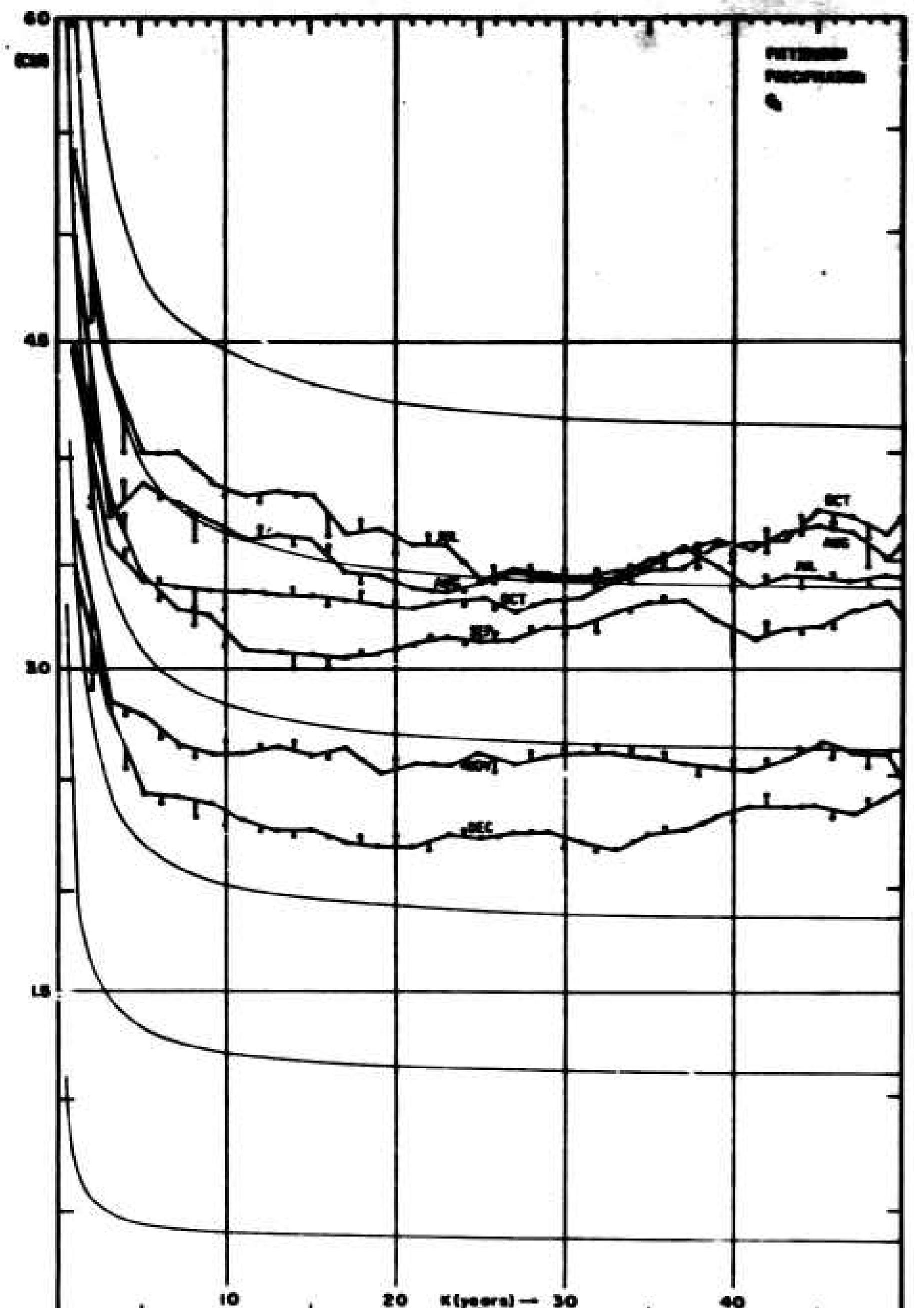


FIGURE 32B

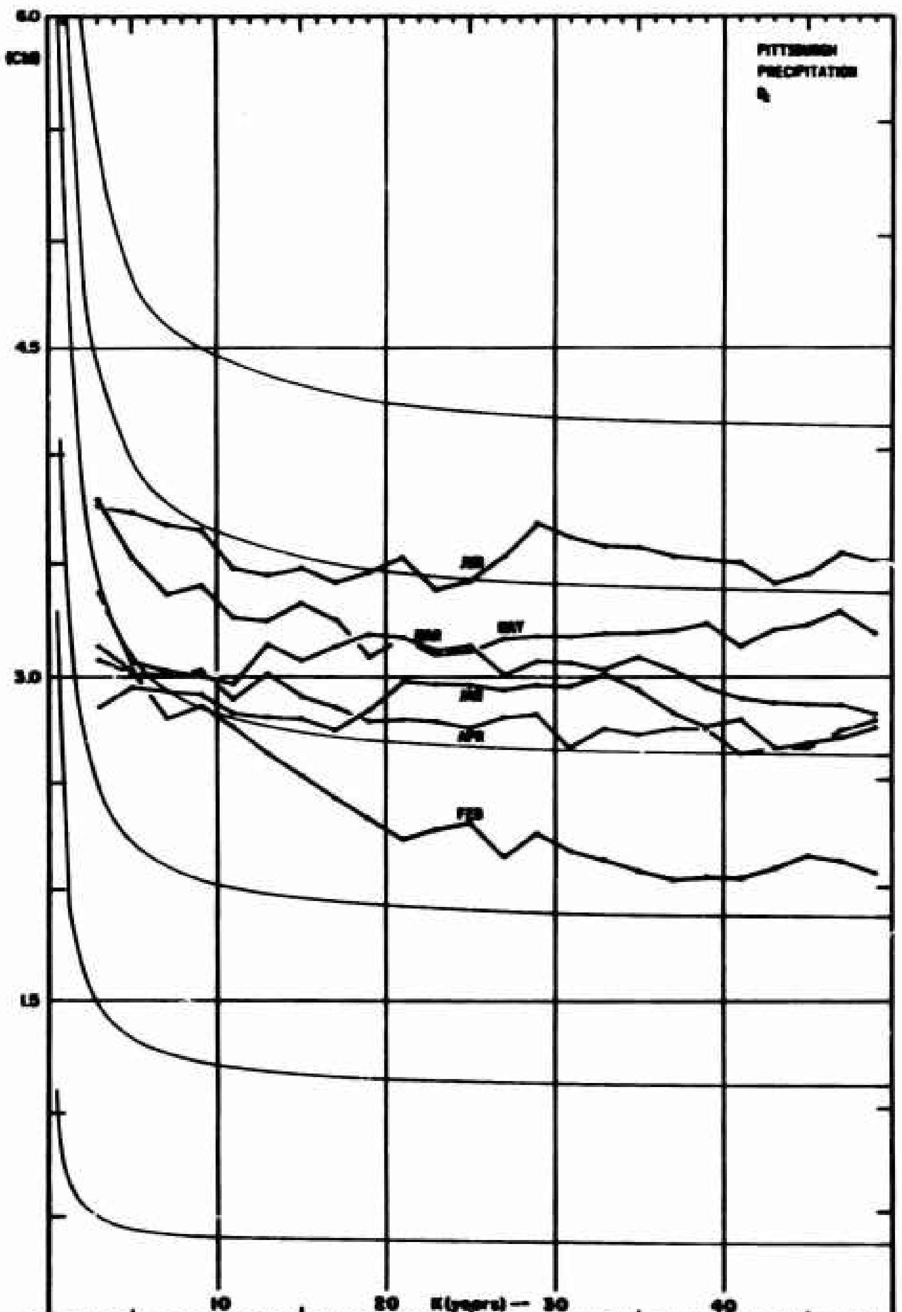


FIGURE [illegible]

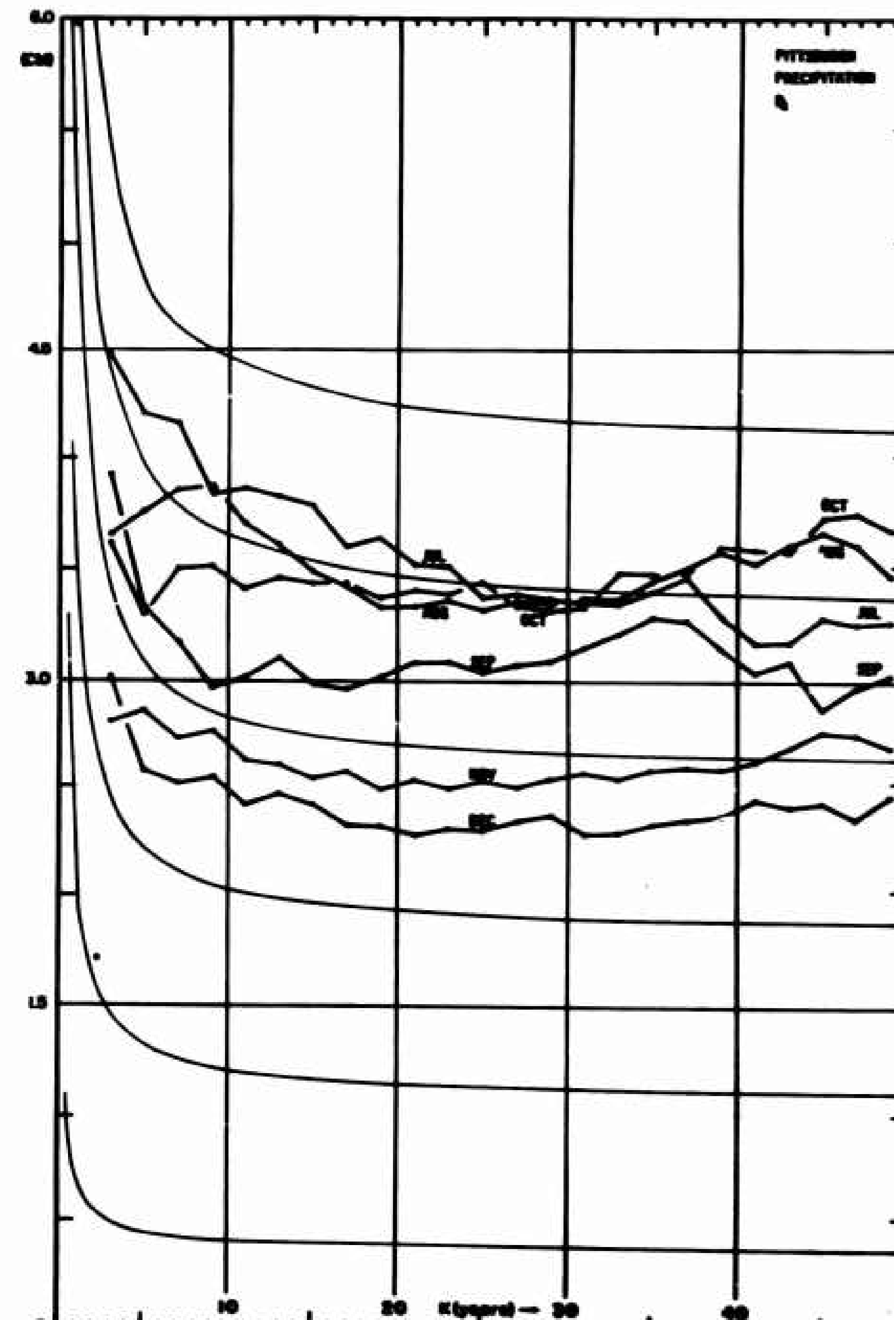


FIGURE [illegible]

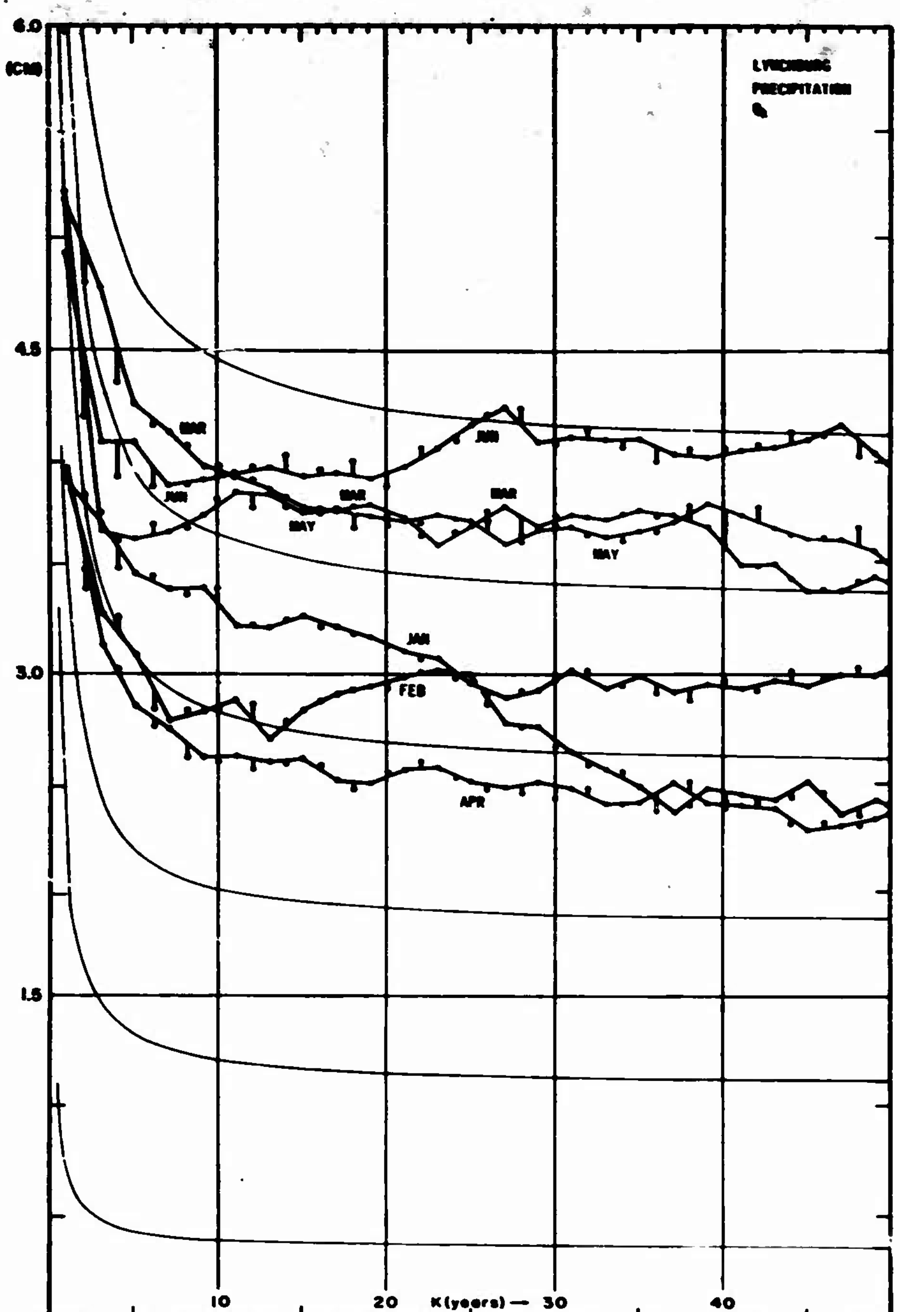


FIGURE 33A

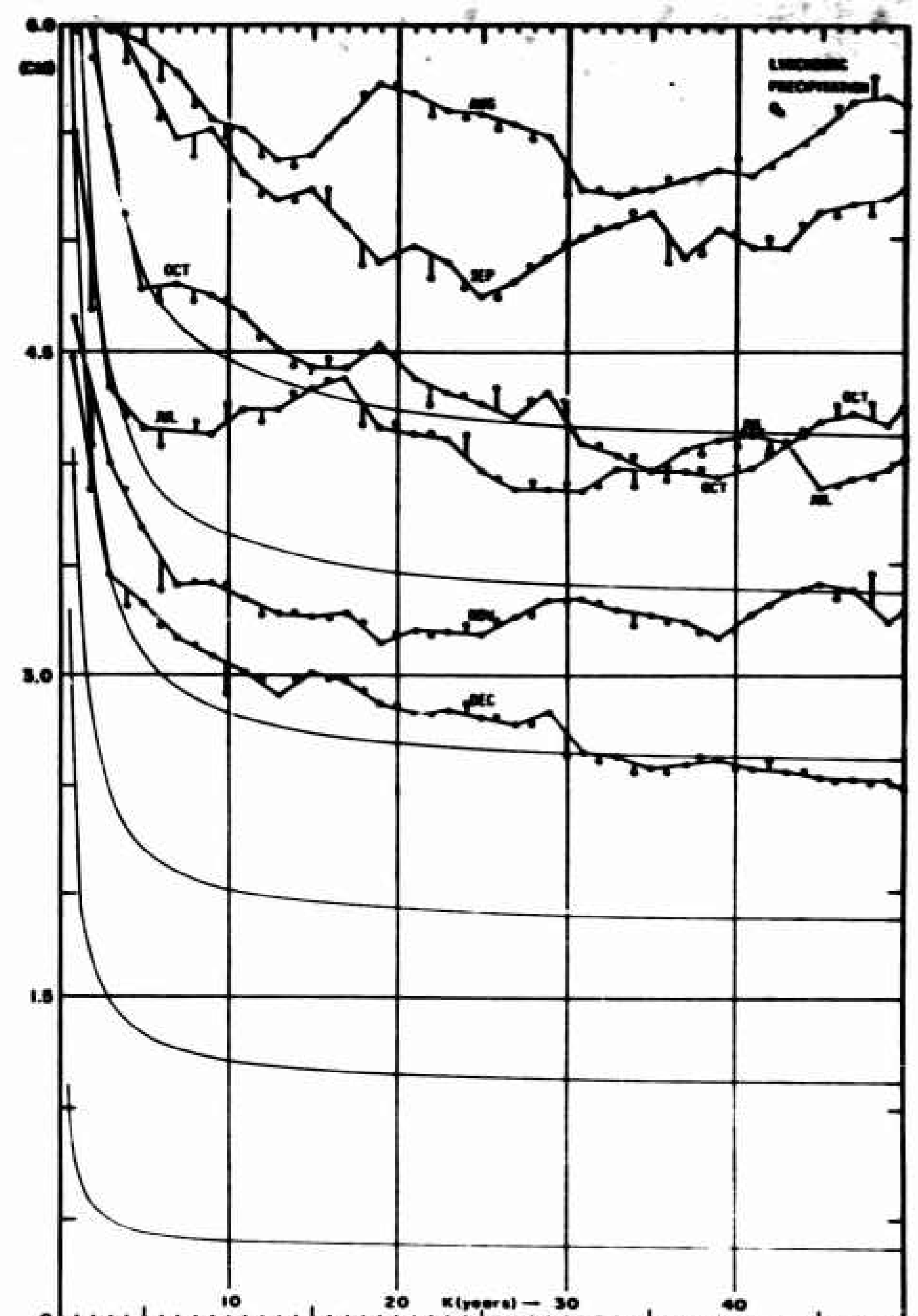


FIGURE 33B

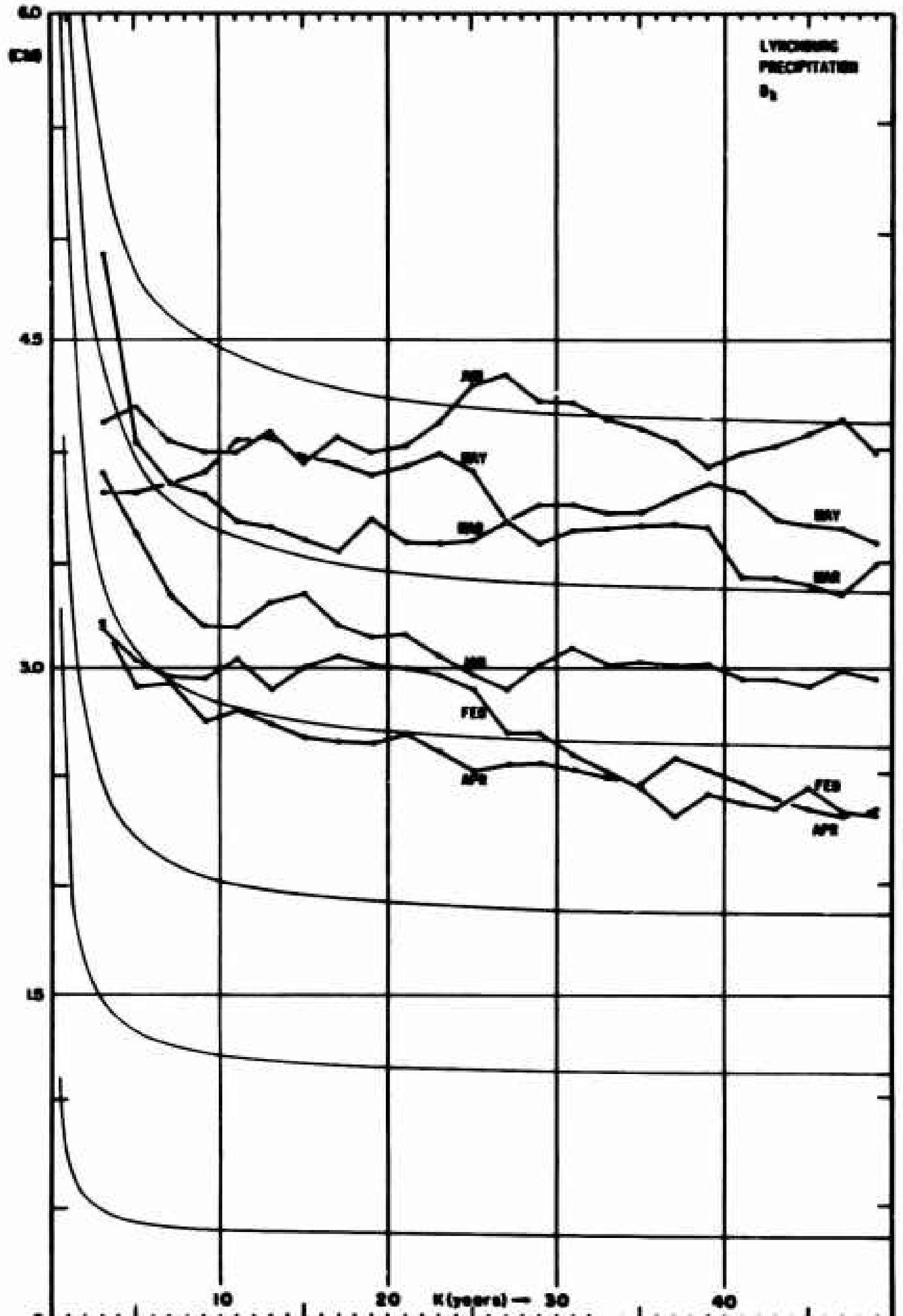


FIGURE 33C

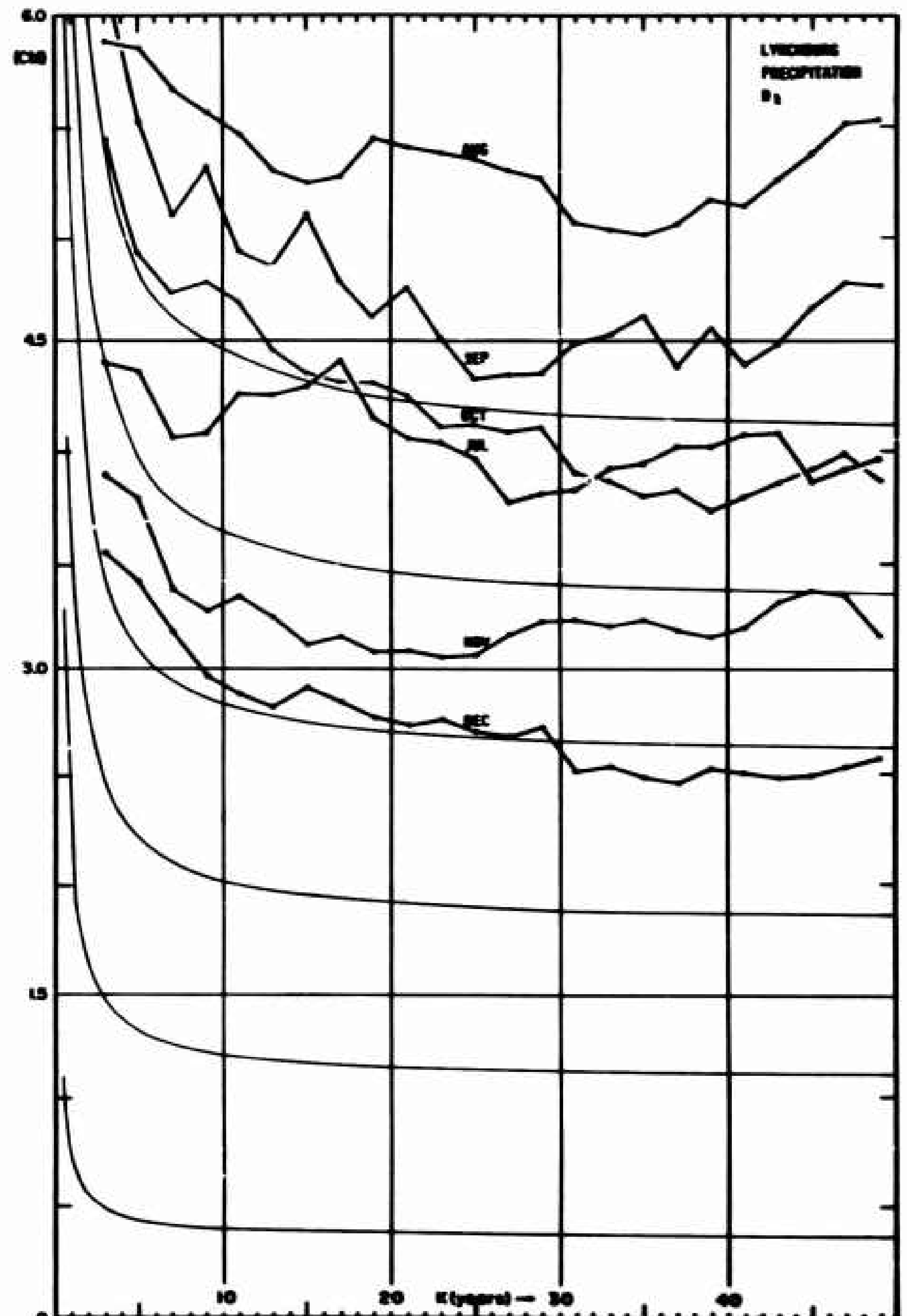


FIGURE 33D

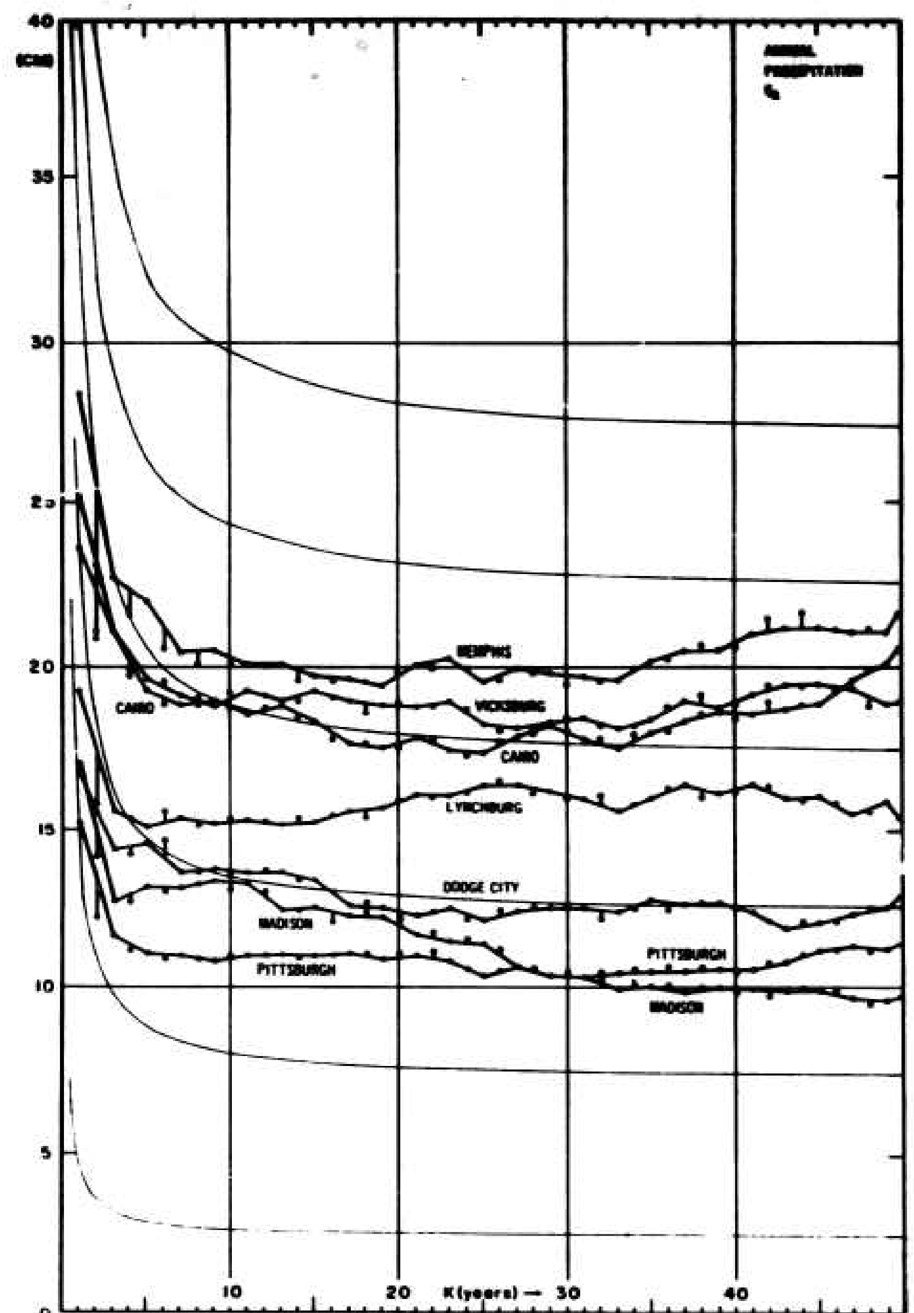


FIGURE 34A

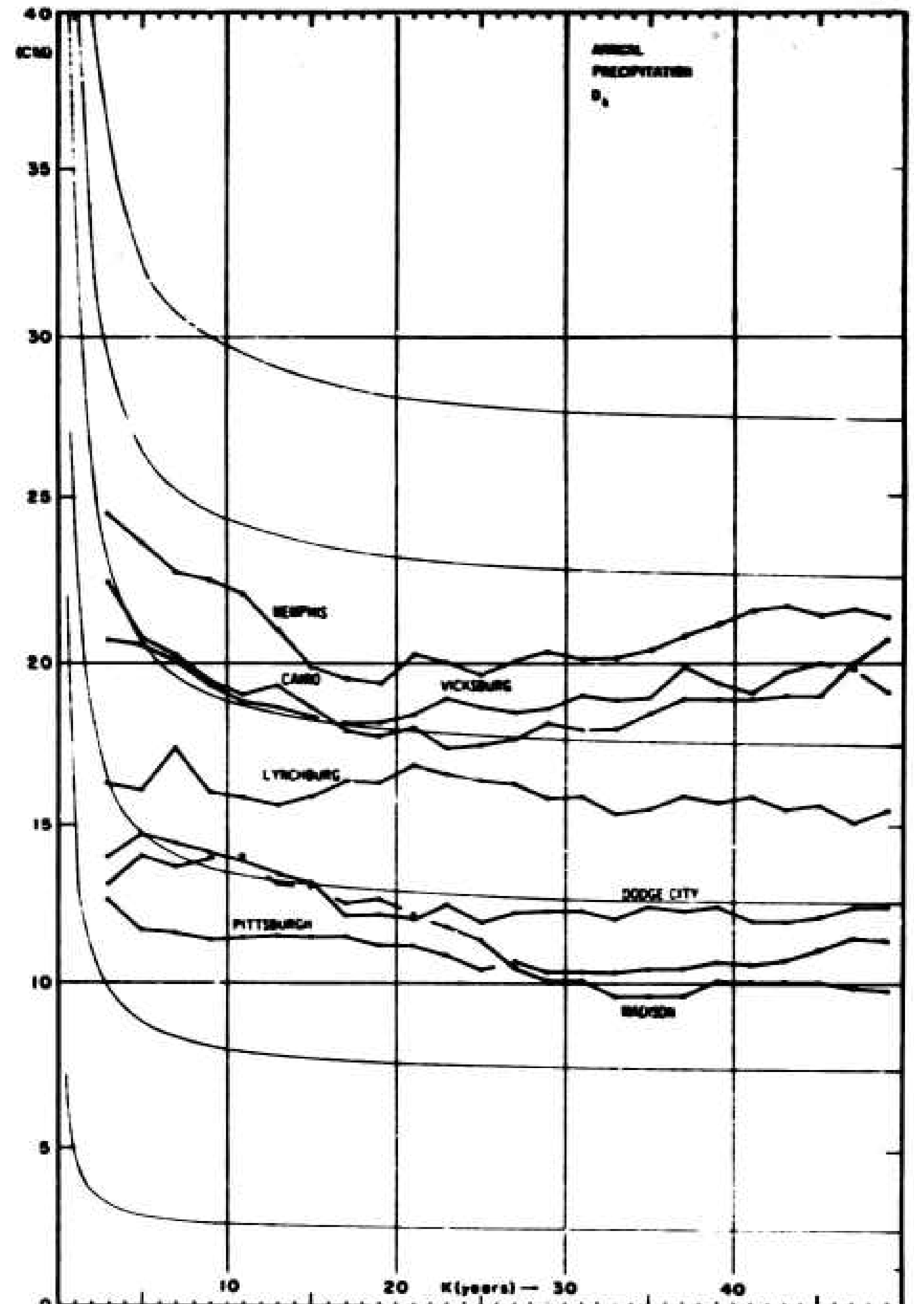


FIGURE 34B

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3 REPORT TITLE

CLIMATIC NORMALS AS PREDICTORS. PART 2: EXTENSION

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific. Interim.

5 AUTHOR(S) (Last name, first name, initial)

Arnold Court

6 REPORT DATE 1 November 1968	7a TOTAL NO OF PAGES 76	7b NO OF REFS none

8a CONTRACT OR GRANT NO. AF19(628)-5716 b Project, Task, Work Unit Nos. 8624-T02-WU 01 c DoD Element 6240539F d DoD Subelement 681000	9a ORIGINATOR'S REPORT NUMBER(S) 82-68-2 Scientific Report No. 2 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-68-0673

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11 SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories L. G. Hanscom Field (CRE) Bedford, Massachusetts 01730

13 ABSTRACT

Temperature and precipitation for a single month or year, picked at random, at each of seven United States stations are found to be estimated as closely, on the average, by the mean of the preceding 10 to 40 years as by a 30-year "normal." The median value for the preceding 15 or so years may be an even slightly better estimator. Graphs show the mean square and mean absolute differences between k-year means and the next observation for k = 1 [1] 50 , and the mean absolute differences between k-year medians and the next observation for k = 1 [2] 49 , for Dodge City, Vicksburg, Memphis, Cairo, Madison, Pittsburgh, and Lynchburg. Comparison of these graphs with corresponding graphs based on random normal numbers, biased in various ways, suggests that many climatic records contain progressive changes in mean or in variance, or both. The number of antecedent years (k*) for which the mean or median is closest to the next year's observation varies erratically from month to month, but tends to be the same at nearby stations for a given month.

DD FORM 1 JAN 64 1473

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Security Classification

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
NORMALS, CLIMATIC						
PREDICTION, CLIMATIC						
OPTIMUM RECORD LENGTH						
MEDIAN						

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